AD-A085 043 VARIAN ASSOCIATES INC BEVERLY MA BEVERLY DIV F/G 9/5

SFD-261 CROSSED-FIELD AMPLIFIER MANUFACTURING TECHNOLOGY PROGRA--ETC(U)

SEP 79 R A LAPLANTE, F E TROJAN N00123-77-C-1019

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REPORT 22-3040 FNL LEVEL II

(12)

SFD-261 CROSSED-FIELD AMPLIFIER MANUFACTURING TECHNOLOGY PROGRAM

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R.A. LAPLANTE AND F.E. TROJAN

VARIAN ASSOCIATES, INC.
BEVERLY DIVISION
EIGHT SALEM ROAD
BEVERLY, MASSACHUSETTS 01915

16 MAY 1980

FINAL REPORT--AUGUST 1977 - SEPTEMBER 1979

PREPARED FOR:

NAVAL REGIONAL PROCUREMENT OFFICE
LONG BEACH, CALIFORNIA 90801

NAVAL OCEAN SYSTEMS CENTER
271 CATALINA BOULEVARD
SAN DIEGO, CALIFORNIA 92152

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
(14) 22-3040-FNL

2. GOVT ACCESSION NO.
AD-A085 043

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SFD-261 CROSSED-FIELD AMPLIFIER MANUFACTURING TECHNOLOGY PROGRAM,

5. TYPE OF REPORT & PERIOD COVERED
(9) FINAL REP[redacted]T,
Aug 77-Sep 79

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) R.A./LAPLANTE
F.E./TROJAN

8. CONTRACT OR GRANT NUMBER(s)
(15) N00123-77-C-1019

9. PERFORMING ORGANIZATION NAME AND ADDRESS
VARIAN ASSOCIATES, INC./BEVERLY DIV.
EIGHT SALEM ROAD
BEVERLY, MA 01915

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
N00953-7-009044-JCE

11. CONTROLLING OFFICE NAME AND ADDRESS
NAVAL REGIONAL PROCUREMENT OFFICE (11)
LONG BEACH, CALIFORNIA

12. REPORT DATE
28 SEP[redacted]79

13. NUMBER OF PAGES
93

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA BOULEVARD
SAN DIEGO, CA 92152 (12) 101

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

16. DISTRIBUTION STATEMENT (of this Report)

UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

UNLIMITED

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

MICROWAVE, AMPLIFIER, RADAR, ASSEMBLY, BRAZING, MACHINING, NUMERICALLY-CONTROLLED, COST REDUCTION, SELF-JIGGING, PRECISION, REPAIRABILITY, PILOT RUN, POWER OUTPUT, EFFICIENCY, NOISE, PHASE.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of the MT program is to demonstrate improved production techniques by a pilot production run of ten (10) tubes to meet performance specification and system compatibility criteria under production line conditions.

The SFD-261 is a microwave amplifier used to increase the power level of pulses of energy by a factor of 20. It is used in the Aegis AN/SPY-1

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radar transmitter. A single ship's complement without spares is seventy-six. Its internal parts are made from high purity copper and many are complex and involve high precision. Most of the fabrication is by precious metal brazing in hydrogen or in vacuum. Modest production rates (10 to 30 units per month) presently restrict the amount of automation which can be effectively applied.

Nearly 30 design changes were made without altering performance significantly. Self-jigging techniques permitted assembly by lower skill levels. A "one-shot" vacuum braze for the cathode produced significant cost and equipment reduction. If the selling price of the standard design is normalized at 100, the price of the MT design is now 57. Because of the number of tubes per ship, with spares, the savings per ship will approach $1 million.

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PREFACE

An engineering program was carried out under Navy contract N00123-73-C-1701 from the Naval Regional Procurement Office, Los Angeles to establish the feasibility of certain cost reduction measures which can be applied to the SFD-261 crossed-field amplifier (CFA). The program was directed by the Naval Ship Weapon Systems Engineering Station, Port Hueneme, California with assistance from the Naval Weapon Support Center, Crane, Indiana. The program was conducted from 18 June 1973 and 31 August 1974.

In carrying out the program, certain of the design changes which were considered had the goal of reducing the skill level required for assembly. These changes (and all the others, in fact) were actually carried out by the highest assembly skill levels we have in order to exercise maximum cost control over the cost reduction program itself by minimizing shrinkage. This was necessary because of the contract form under which the work was done. Unfortunately, this did not represent a confirmation or proof that lower skill levels can, in fact, be used without jeopardizing yield. Such proof would require a subsequent pre-production lost to be manufactured.

The program was divided into five tasks.

Task I was a redesign of the cathode and pole piece subassemblies to reduce parts cost and assembly time. This was considered not to affect performance or life and was evaluated on one tube.

Task II was a redesign of the input and output transformer assemblies to reduce parts cost and assembly time. Because this may change RF performance (but not life), it was evaluated in two tubes.

Task III was a redesign of the cathode-anode space and a redesign of the input-output match both of which were an attempt to reduce phase-frequency excursions. Lack of control in that design of these excursions had required the opening of the phase similarity specification from $\pm 10°$ to $\pm 25°$. Yield in this area was very poor for a $\pm 10°$ specification and the reduction of the excursions was aimed at improving this yield.

Task IV was the building of two tubes which incorporated the best features of Tasks I, II and III into a composite design and evaluating them.

Task V was a study.

Testing of tubes in Tasks I, II and III was in accordance with the DOOEMA-2-TP test procedure. Task IV tubes used the DOOEMQ-1-TP procedure. The tubes actually built are shown in Table I. The changes made in tubes in each of the tasks are described in design evaluation drawings. These drawings are in Varian's format and are shown in Table II which relates the drawing numbers to tube numbers and tasks.

The Task V study was in four parts:

1.) On a continuous basis collect and evaluate other potential cost reduction improvements.

2.) Estimate production rates and order commitments necessary to achieve a $2,500 (1973) unit price.

TABLE I

SUMMARY OF PRIOR COST REDUCTION TUBES BUILT

S/N	TASK NO.	DESIGN CHANGE	TEST DATE
CR-1	III	CATHODE GROOVED	24 OCT. 73
CR-1A	I	COST REDUCED CATHODE/POLE PIECES	11 DEC. 73
CR-2	II	TRANSFORMERS	10 JAN. 74
CR-3	II	TRANSFORMERS	15 FEB. 74
CR-4	III	MATCH	21 MAR. 74
CR-4A	III	MATCH	28 MAR. 74
CR-5	IV	COMPOSITE	20 JUNE 74
CR-6	IV	COMPOSITE	20 JUNE 74

Table II

Design Evaluation Drawing List

Task No.	Tube Number	Design Change	Drawing Number
I	CR-1A	Cathode/Pole Pieces	B380345
			B380346
			B380347
II	CR-2	Transformer	B380343
	CR-3	Transformer	B380344
III	CR-1	Cathode Grooves	B380348
	CR-4	Match	C380397
	CR-4A	Match	
IV	CR-5	Composite	C380397
	CR-6	Composite	B380345
			B380346
			B380347

3.) Recommend solutions to recognized system interface problems (HV cable, etc.).

4.) Study possibilities of eliminating the oxygen dispenser and ion pump.

The reader is referred to the final report on the program for details of the study.

The first conclusion reached on this program is that the cost-reduced tubes are markedly simpler in construction than the standard SFD-261 and should require less assembly labor and of a lower level. Of the design areas which were changed (pole pieces, cathode, transformers) the standard tube contains 135 parts while the cost-reduced tube has 52 parts. A comparison, assembly by assembly, is revealing.

	Number of Parts	
	Standard	Cost Reduced
Top Pole Piece	12	5
Stem Pole Piece	13	5
Cathode Assembly	29	10
Transformer	24	8
Isolated Match	57	24

A second conclusion was that the cost appeared to have been reduced by 20-25% in a quantity of 10 tubes. Using then current material and labor costs (September 1974) for both the standard design and cost-reduced design and assuming the same yield for both (10/13), the standard design would be $13,400 each and the cost-reduced tube would be $10,700 each. It must be noted, however, that we had no experience

with regard to the cost-reduced tube's manufacturing yield using lower skill levels. That lower skill level experience was to become an important part of the Manufacturing Technology Program described in the following report.

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1.0 INTRODUCTION

The SFD-261 crossed-field amplifier (CFA) is a microwave tube which is used in the final power amplifier of the Aegis AN/SPY-1 radar system. A total of 76 of these power amplifiers operate at the same time in the twin transmitters of this radar system. At the current selling price of these tubes of approximately $15,000 each, the acquisition cost of the tube complement for the radar exceeds a million dollars. This cost plus the replacement cost of tubes which wear out can affect the cost of ownership of the system to a degree which is uncommon for microwave components. A great deal of emphasis has, therefore, been placed on life and reliability during the development phase of this amplifier, and now the questions of manufacturing cost are being addressed.

In 1973 and 1974, the Navy supported an SFD-261 cost reduction program at Varian. The outcome of that program was the delivery of two tubes which incorporated a number of significant design changes which Varian estimated would reduce the selling price of the tube by approximately 25% without sacrificing performance, life or reliability. Because the sample of two is a small one, assembly and test of the units was carried out in an environment which was more like development than production. Many of the design changes which were made were intended to enable the assembly to be carried out by relatively low skill level labor. The estimate of a 25% cost reduction was based upon the assumption that lower skill levels can, indeed, be employed without impairing manufacturing yield. This had not yet been demonstrated.

Cost reduction measures which were addressed in the previous program were believed to represent a fairly large fraction of the ultimate cost reduction possible for the quantity commitments and delivery rates which were assumed. The balance of the potential cost reduction measures were restricted in that program to a study which would identify areas which remained to be addressed.

The objective of the present program is, therefore, to address those remaining cost reduction areas and to build a larger sample of ten tubes in an environment which is production and not development, and in which the labor skill levels employed are the lower levels for which the design was tailored. From the ten tube output of the program we then want to demonstrate that a cost reduction of between a third and a fourth has, indeed, been realized.

The program was started in August 1977 and was scheduled for 15 months. The contract is a cost-plus-fixed-fee contract for $218,519 including fee. Technical direction is given by the Naval Ocean Systems Center, San Diego, California. Several no-cost time extensions were requested and granted which extended the program to a total of 24 months duration. The delays were generated in two ways: certain material, especially forgings, took many more months to obtain than had been forecast; and a technical problem developed (Silastic failure) which was common to this and other programs (Aegis production) which forced us to put a hold on the MT program until the problem was solved. This problem will be discussed later.

Several important assumptions had to be made in determining the approach to be taken in this program. First, because costs are driven so strongly by quantity, it was necessary to establish what the likely production commitment quantities would be and what the likely delivery rates would be. We assume that deliveries will be between 10 and 20 tubes per month, and that appears in the present forecast to be an accurate assumption. We also assume that individual production commitments would be made for a quantity of 100 to 200 tubes. This too appears to be relatively accurate. We allowed that the design changes we made could make the tube incompatible with the present EDM-1 transmitter aboard the U.S.S. Norton Sound if the cost reduction benefits were significantly great. We would then have established the design for the production systems produced thereafter. It was necessary to assume that any design changes which were made would impair neither the present life of the tube nor the repairability of the tube. These two factors are quite important in the cost of ownership calculation for the system.

The principle areas of effort are the use of stampings, castings and forgings in the fabrication of parts, the use of numerically-controlled (N/C) machining operations, the simplification of certain vacuum brazing procedures especially related to the cathode of the tube, modifying the design of assemblies to enable lower skill levels to be used, and finally to build the ten-unit sample of tubes. That sample will be used to demonstrate an acceptable yield, to show electrical performance is unchanged, to establish compatibility with the system, and to reconfirm the life and reliability of the new design.

The crossed-field amplifier utilizes traveling wave interaction in an electronic system in which electron velocities are at right angles to the magnetic field (or crossed) as opposed to the conventional traveling wave tube in which the velocities and the magnetic field are co-linear. This crossed-field interaction is what gives the device its high efficiency. The SFD-261 shown in Figure 1 is essentially a cylinder six inches in diameter by about 12 inches long with input and output waveguides protruding from the cylinder. It mounts vertically as shown in the Aegis system. The high voltage is applied through the cable at the side of the tube. The tube complete with its permanent magnets enclosed weighs about 45 pounds. Its relatively high price results principally from the large number of precision parts required, rather intricate assembly procedures, and the fact that production rates have been very modest. The major elements of the unit can be seen in the exploded view of Figure 2. The core of the tube is in the body waveguide assembly and the cathode between which all of the electronic interaction takes place. These two pole piece assemblies and permanent magnet cylinders provide the needed magnetic field for the crossed-field interaction. The two halves of the magnetic can provide the return path for that magnetic field. Coolant which comes in contact with the high voltage cathode is isolated from ground by an insulating coolant coil around the high voltage ceramic insulator. This coil also acts as a load for RF radiation from the stem to eliminate radio frequency interference in the system.

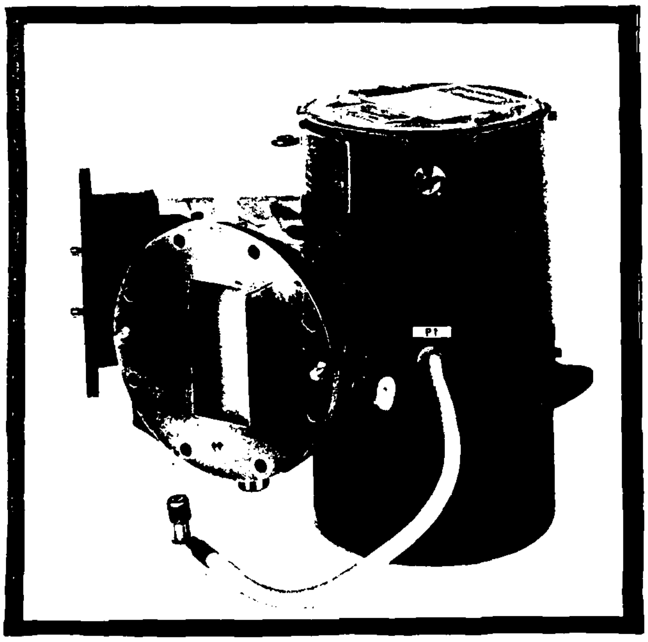
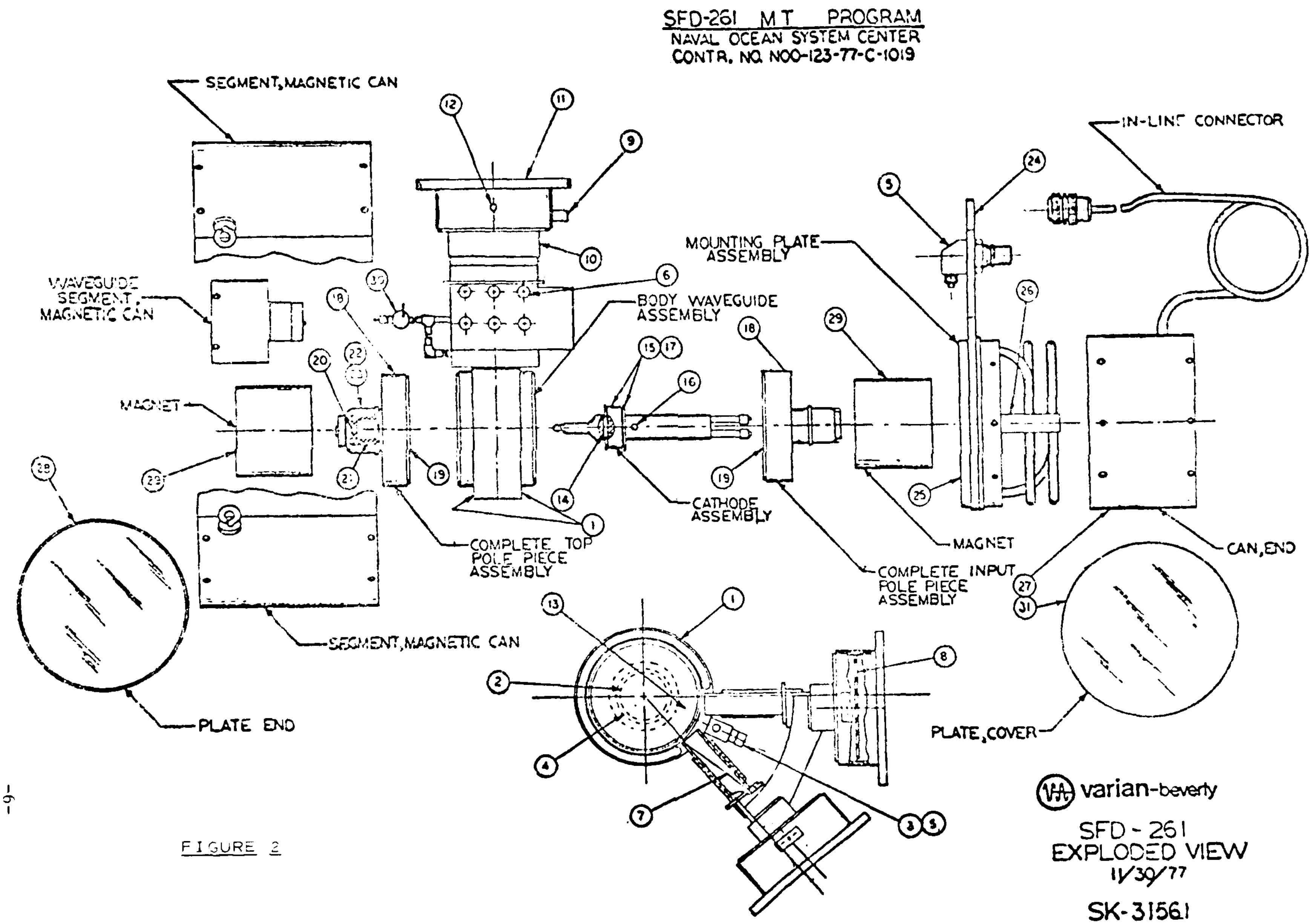


FIGURE 1

SFD-261 CROSSED-FIELD AMPLIFIER


SFD-261 M T PROGRAM
NAVAL OCEAN SYSTEM CENTER
CONTR. NO. N00-123-77-C-1019
SEGMENT, MAGNETIC CAN
IN-LINF CONNECTOR
MOUNTING PLATE ASSEMBLY
WAVEGUIDE SEGMENT, MAGNETIC CAN
BODY WAVEGUIDE ASSEMBLY
MAGNET
CATHODE ASSEMBLY
COMPLETE TOP POLE PIECE ASSEMBLY
MAGNET
CAN, END
COMPLETE INPUT POLE PIECE ASSEMBLY
SFGMENT, MAGNETIC CAN
PLATE END
PLATE, COVER
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SFD - 261
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FIGURE 2

The principle design areas addressed during the previous program involve the two pole piece assemblies, the cathode assembly and the waveguide portion of the body waveguide assembly. Changes to the body portion of the body waveguide assembly (which contains the slow wave circuit) were deliberately avoided in order not to compromise the RF performance of the tube. One significant exception to that was the interface between the body assembly and the waveguide assembly where the RF impedance transformation is begun between the slow wave circuit and the first step (nearest the body) of the ridged-waveguide impedance transformer. This area was redesigned and became known as the isolated match design. This will be discussed later in comparing MT tube performance to that of lead ship tubes (DDG-47). In the current work an additional 30 different possible design changes were identified and were studied for possible incorporation into the tube. A number of these have fallen out as being trivial and others fell out because of technical difficulties with their implementation.

A number of program reviews were conducted during the term of the program: 8 December 1977, 15 March 1978, 13 July 1978, 2 November 1978, 28 February 1979 and finally an End-of-Project Demonstration on 31 May 1979. These were all held at Varian/Beverly and involved various combinations of Navy/Industry representatives from the MT and Aegis communities.

In the remainder of the report we shall discuss the 30 mechanical design changes in Section 2; the Navy-sponsored Noise Improvement Program and its relationship to this one in

Section 3; the Raytheon-directed Vane Tip Improvement Program and its effect in Section 4; and a brief discussion of the Silastic* problem and its schedule impact on MT in Section 5. In Section 6 we shall discuss delays caused by phase measuring equipment and in Section 7 we shall compare average performance of the MT tube against lead ship tubes and EDM-1 tubes. (A total of 70 tubes were delivered to Raytheon in 1971-1972 for use in the first engineering development model of the system--EDM-1.) In Section 8 we shall present a summary of the cost comparisons made at the close of the program. Details of this analysis will be presented in a separate Cost Analysis Report, to be published concurrently with this one. Section 9 will present the plan presented by the Naval Weapons Support Center/Crane for the evaluation/qualification of the MT tube design. Section 10 will discuss the repairability of the tube, and Section 11 will present conclusions and recommendations.

*Trademark of Dow Corning

2.0 MECHANICAL DESIGN CHANGES

Before discussing the mechanical design changes in detail we shall list them with a brief description. The area of the tube involved can be found in Figure 2 by finding the list number as a number callout in the figure. The proposed changes were:

1. Body coolant channel cover seat presently milled will be turned. Saddle block for entering and exiting coolant will be eliminated and coolant channels cover will be changed.

2. The molybdenum tip ring keeper will be made as a casting. A material change may also be required.

3. Change exhuast port arrangement to present SFD-261H design. (See also change #13.)

4. Slot helix blank a full 360° instead of the present 310° to eliminate start/stop tolerances.

5. Change mounting block from monel to cupro-nickel.

6. Eliminate holes from waveguide stiffener. Consider using cupro-nickel.

7. Use a forged waveguide transformer blank prior to numerically-controlled (N/C) milling.

8. Purchase ceramic windows pre-metallized. Consider lower purity ceramic.

9. Modify window cylinder pins for mounting plate block.

10. Modify window to waveguide adapter for forging or hobbing and N/C machining.

11. Dowel holes in flange piece part--use forged blank.

12. Modify window cylinder vent hole.

13. Modify drift block venting.

14. Change hole in cathode support pivot from a milled hole to a drilled hole.

15. Make one-shot matrix and end hat braze to eliminate two vacuum brazing operations.

16. Eliminate holes in cathode support cylinder.

17. Change cathode height tolerance.

18. Make heliarc from cast or forged blank.

19. Change Consumet iron pole piece from flat stock to bar stock.

20. Simplify shape of cathode support ceramic.

21. Change bellows from monel to stainless steel and modify design.

22. Change material for support ceramic retainer.

23. Simplify top pole piece construction.

24. Make mounting plate from stamped or cast blank.

25. Make support mounting plate from cast blank.

26. Cooling tubing support--change to nylon.

27. Make bottom cap of one spun part. Use separate plastic keeper for Silastic mold.

28. Simplify top plate of package and use stock thickness.

29. Relieve magnet tolerances.

30. Eliminate two liter pump.

As the study of the proposed changes proceeded, some were eliminated from consideration. Figure 3 lists those changes which were incorporated into the 10-tube lot and those which were eliminated. The reasons for their elimination will be discussed as the individual changes are described in greater detail, as follows.

1. Anode Body--The anode body is the part into which the RF slow wave circuit is later brazed; which contains the coolant fittings and coolant channels; and through which RF input and RF output power pass through openings called irises. (Electrically, the iris is a short, 1/4", length of ridged waveguide.) The changes made in this part are shown in the next six figures. Figure 4 shows the differences in the initial turning operations. In the standard design a seat was turned on each side of the part to accept a pair of cylindrical heliarc flanges, and a seat for the slow wave circuit. In the MT design two other turning operations on each side of the part provide a seat for a coolant channel cover and a seat for brazing wire to be added later.

The first milling operation on the part is shown in Figure 5. On the standard design, the coolant channel and the seat for the coolant channel cover are milled. On the MT design, only the coolant channel is milled, the seat having previously been turned.

The second milling operation, in Figure 6, adds to the standard design three holes in the coolant channel plus two seats

MT PROGRAM

PROPOSED CHANGE STATUS

	INCORPORATED CHANGES		ELIMINATED CHANGES
# 1	ANODE BODY	# 2	KEEPER (CAST)
3-13	EXHAUST ARRANGEMENT	7	FORGED TRANSFORMER BLANK
4	HELIX MACHINING	8	LOWER PURITY CERAMIC
5	MOUNTING BLOCK	18	CAST HELIARCS
6	WAVEGUIDE STIFFNER	19	MAGNETIC CAN
8	CERAMIC WINDOW METALLIZED	21	BELLOWS
9	WINDOW BLOCKS	23	TOP POLE PIECE CONSTRUCTION
10	WINDOW W/G ADAPTER	24	STAMPED MOUNTING PLATE
11	DOWEL HOLES	30	2 LITRE PUMP
12	WINDOW VENT HOLE		
14	CATHODE SUPPORT		
15	ONE SHOT MATRIX BRAZE		
16	CATHODE SUPPORT CYLINDER		
17	CATHODE TOLERANCES		
20	SIMPLIFY CATHODE SUPPORT		
22	SUPPORT RETAINER		
25	SUPPORT MOUNTING CASTING		
26	TUBING SUPPORT		
27	HIGH VOLTAGE CAN END		
28	TOP PLATE		
29	MAGNET TOLERANCES		

FIGURE 3

LIST OF CHANGES WHICH WERE INCORPORATED INTO THE 10-TUBE LOT AND THOSE WHICH WERE CONSIDERED AND ELIMINATED.

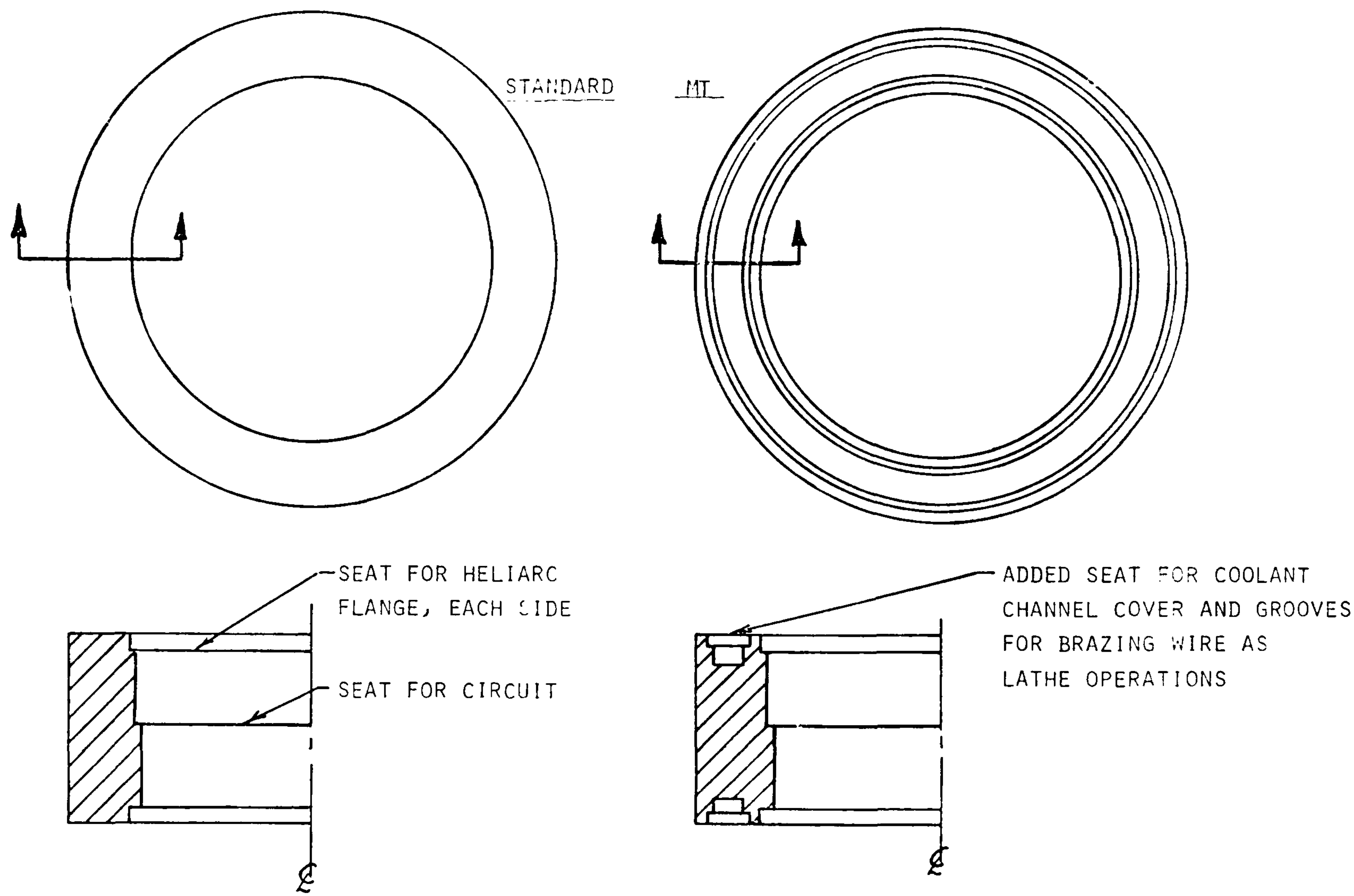

FIGURE 4--ANODE BODY AFTER TURNING OPERATIONS

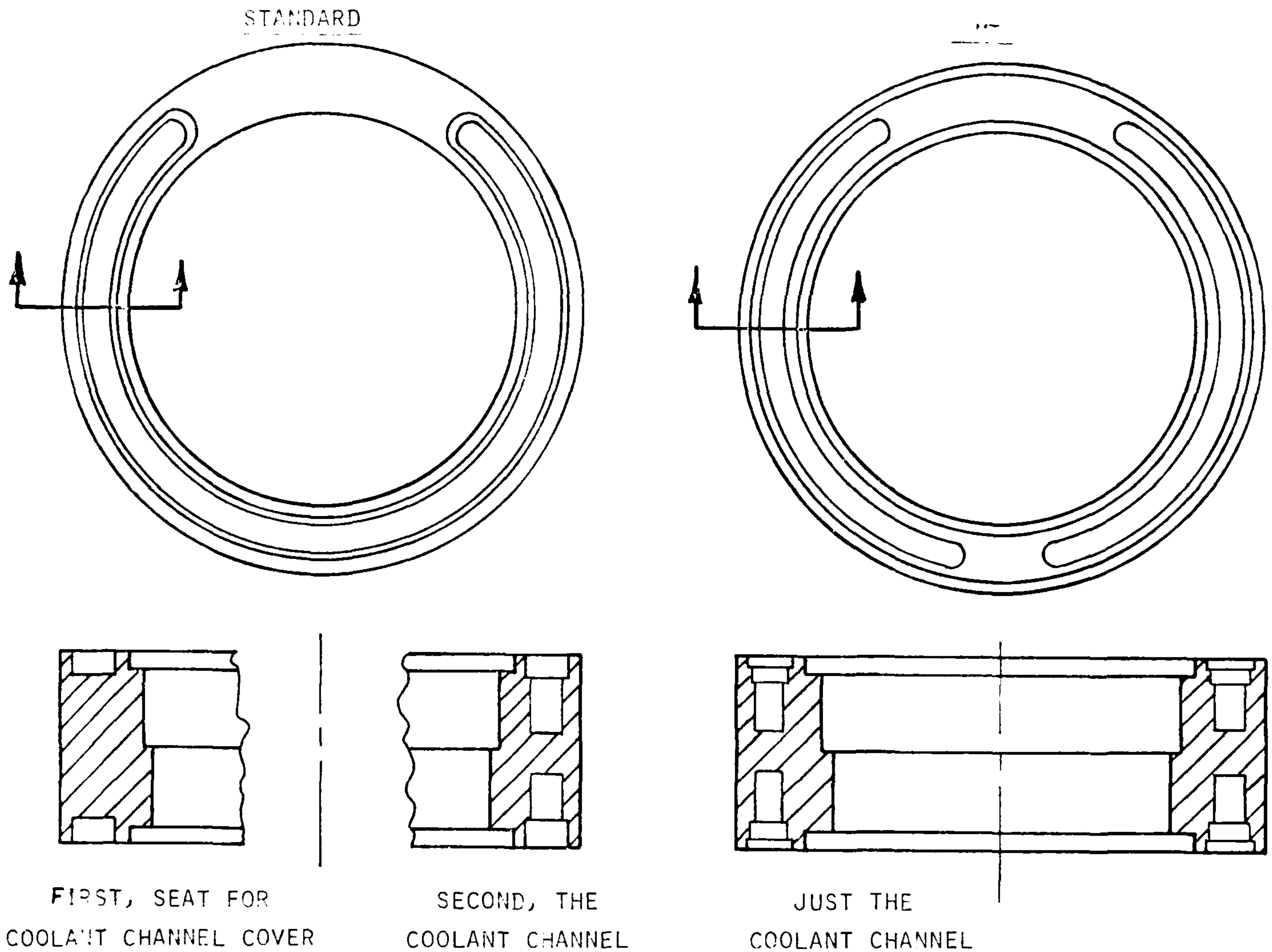

FIGURE 5--ANODE BODY AFTER FIRST MILLING OPERATIONS

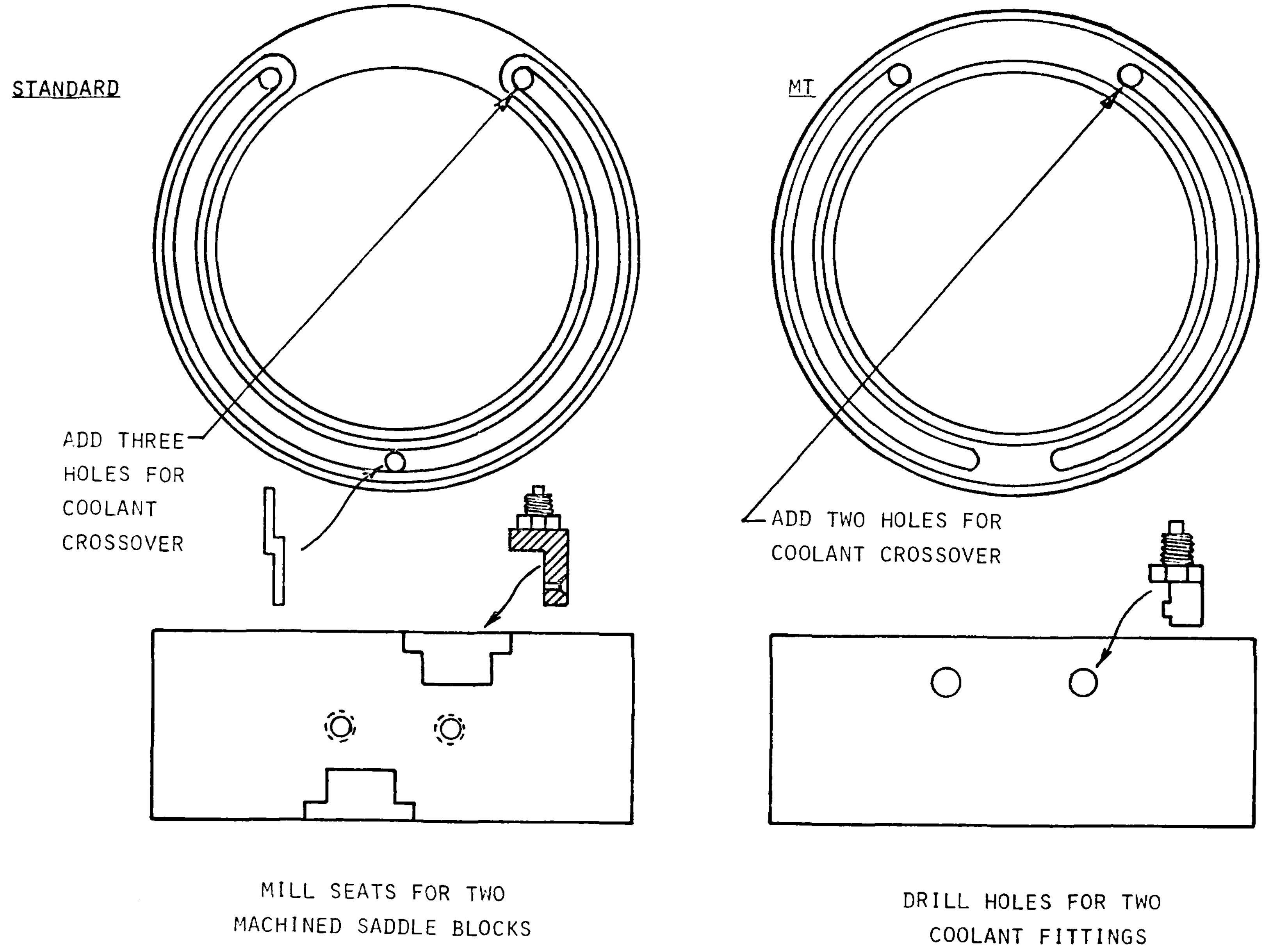

FIGURE 6--ANODE BODY AFTER SECOND MILLING OPERATIONS

for coolant saddles to be brazed. This also involves drilling and tapping two blind holes. In addition, another part, a baffle, must be added to divert coolant flow. Only two holes are required in the MT design, and the coolant fittings are brazed directly into the holes.

Figure 7 shows the difference in the coolant routing between the standard and MT designs.

The standard design calls for a broached iris as shown in Figure 8. The MT design has a milled iris with rounded interior corners.

The coolant channel cover of the standard design in Figure 9 is first stamped out as a ring and two grooves are turned in it for brazing wire. The cover is then parted into 2 pieces as shown. The MT cover is a simple stamping; half the number of parts and reduced set up time for the braze. This series of changes produced a major cost reduction.

2. Spline Blank Keeper--During the fabrication of the slow wave circuit, a preliminary subassembly is furnace brazed (see Figure 10) with a stainless steel keeper (low thermal expansion) used to constrain the thermal expansion of the copper spline (circuit blank). It was felt that costs could be reduced if the keeper were machined from a casting or forging, and the initial response from one vendor tended to confirm that. When prices were formally solicited, however, only one vendor responded and he with prices twice those he had first indicated. Tooling

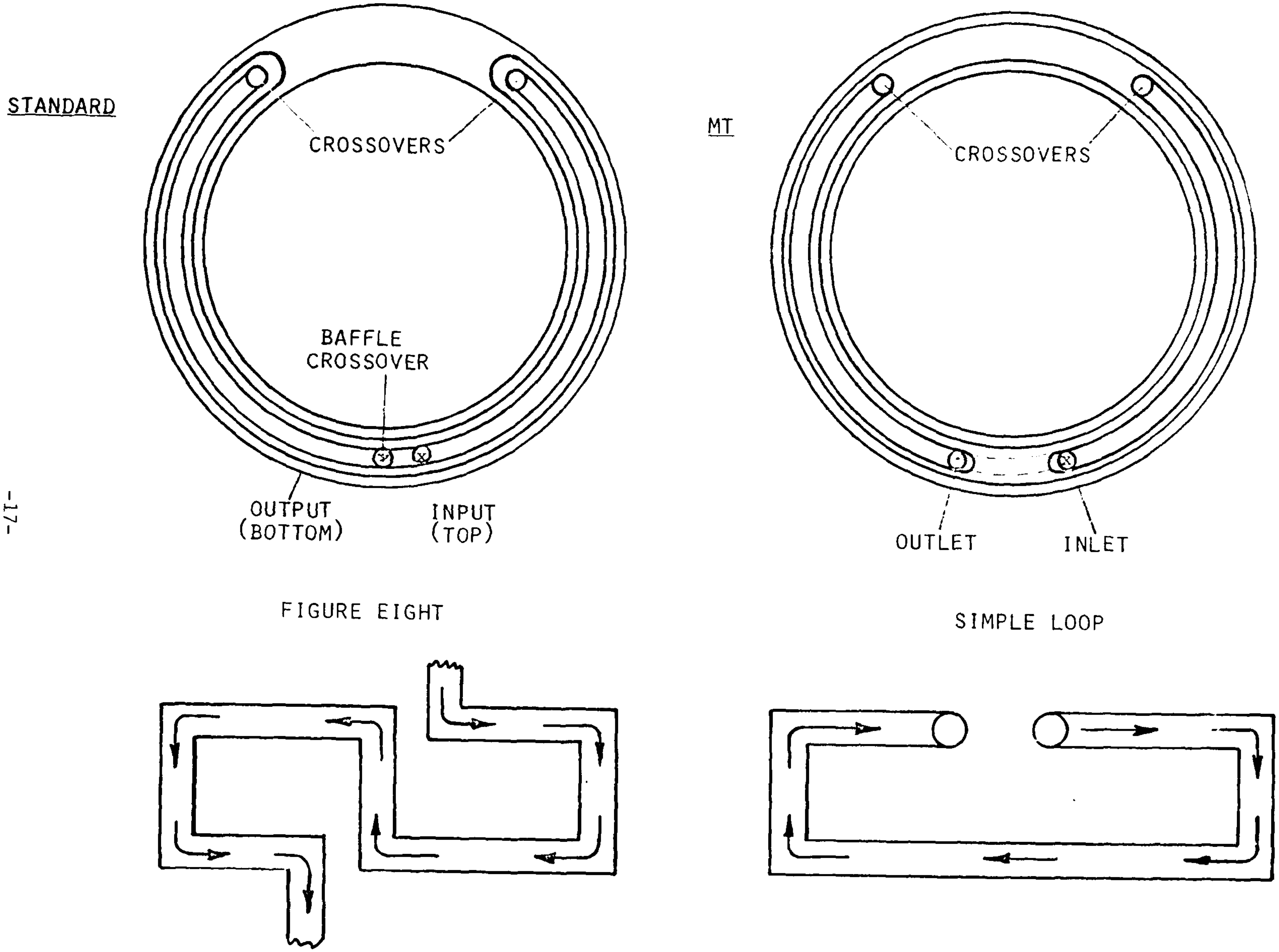

FIGURE 7--ANODE BODY SHOWING COOLANT ROUTE

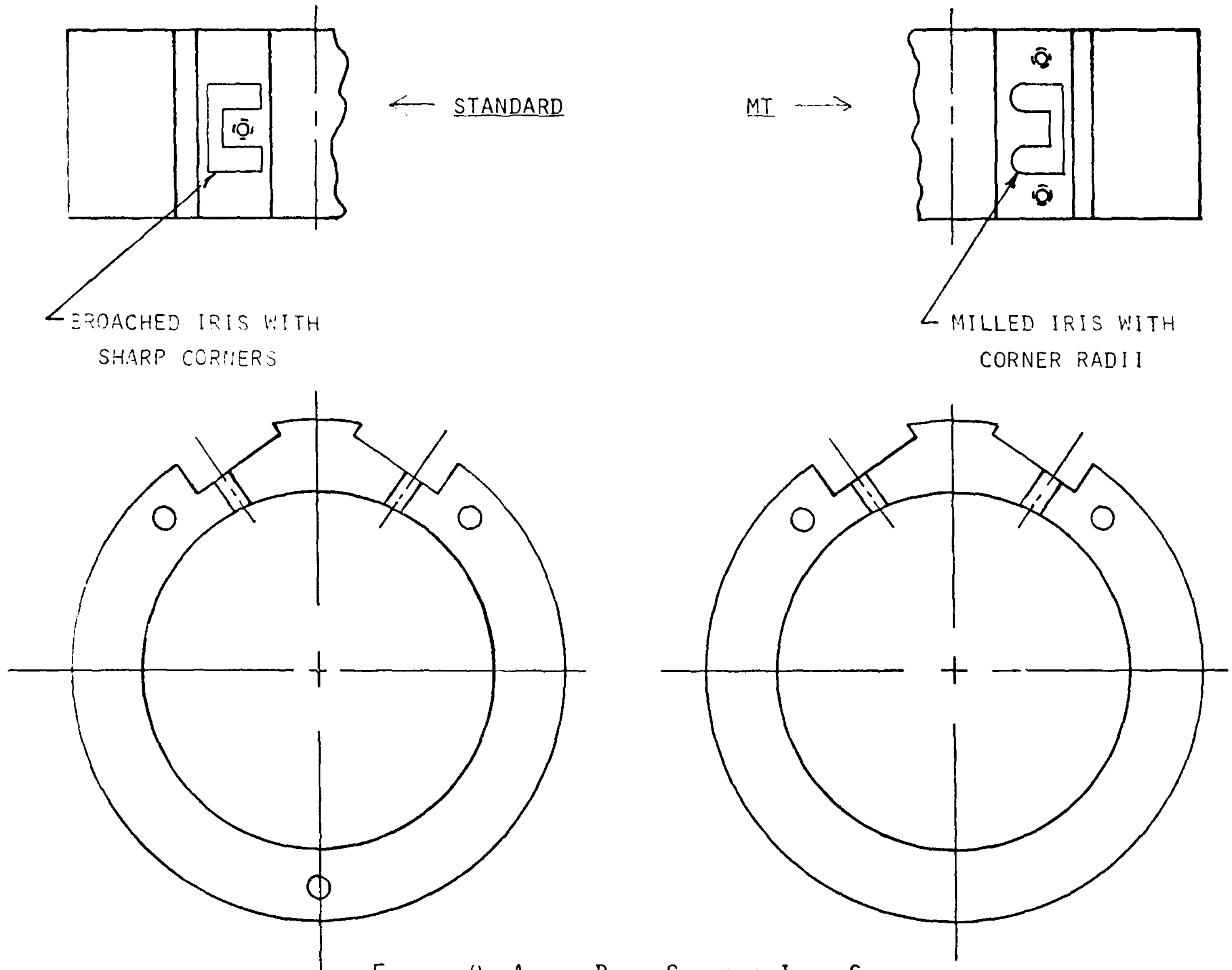

FIGURE 8--ANODE BODY SHOWING IRIS CHANGE

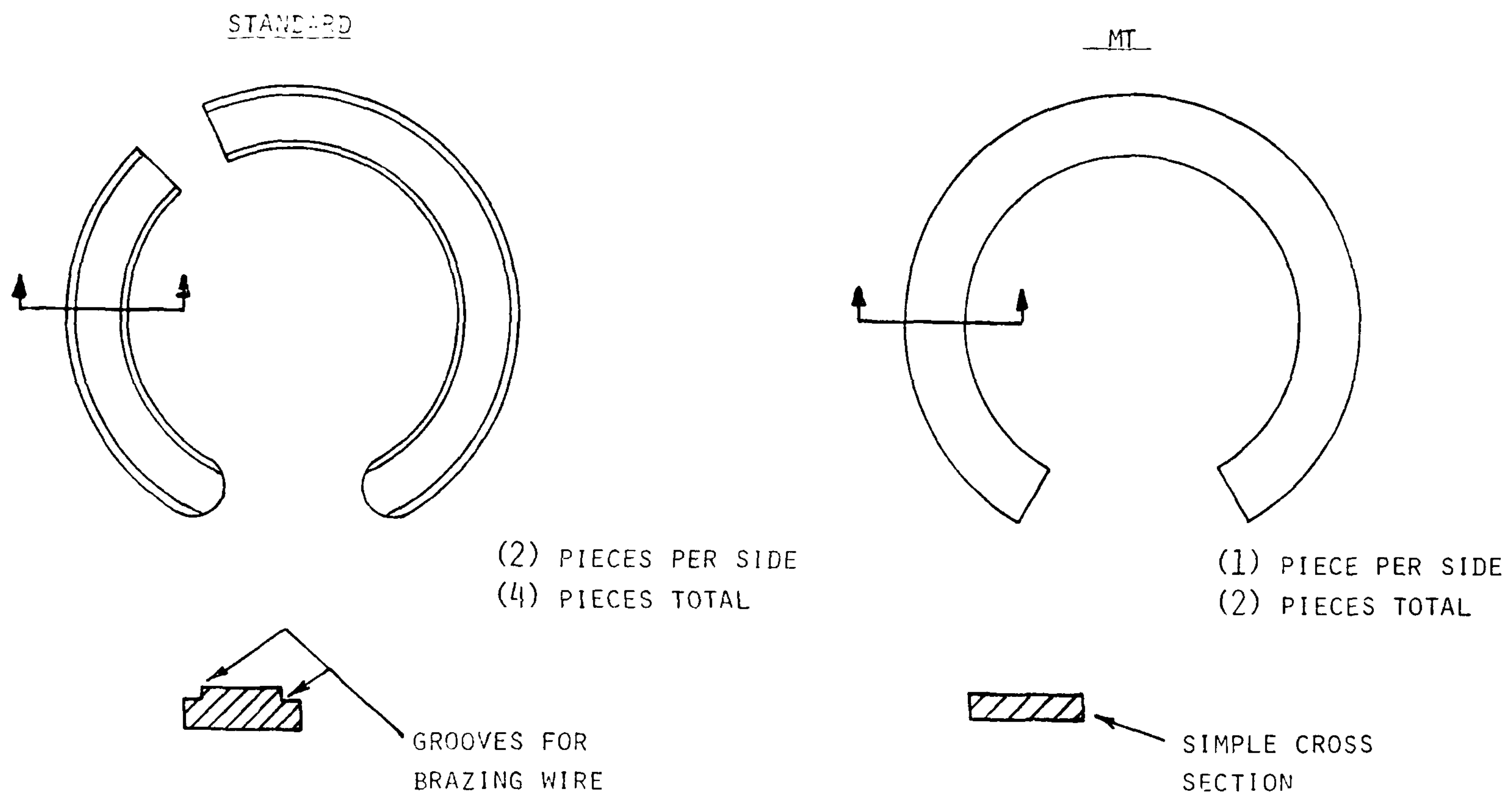

FIGURE 9--COOLANT CHANNEL COVER

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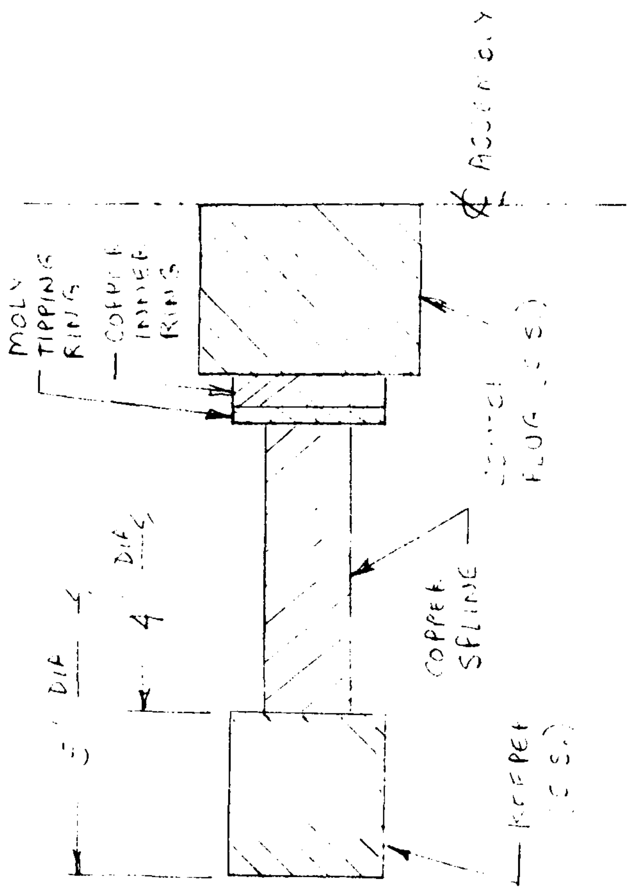

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ENGINEERING SKETCH

TITLE SPLINE BLANK KEEPER

SK FIGURE 10

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charges for the small numbers of parts involved made this change ineffective and it was not pursued.

3.-13. Exhaust Arrangement--In the redesign which produced the isolated match on the first cost reduction program and which is used in the MT design, the exhaust port through which the tube is pumped was partially blocked and gas from inside the tube had to flow through relatively small passages before reaching the exhaust port. The change was intended to improve yield by improving performance even though the change increased fabrication cost. This at one time was suspected of contributing to gassiness in the tubes. As shown in Figure 11, the exhaust arrangement was returned to that used in the standard design, but the cost saving was trivial.

4. Helix Machining--Machining of part of the circuit helix shown in Figure 12 consisted in the standard design of slotting around all but 50° of the circumference of a ring. The 50° sector was to be the drift region. Having the part slotted around 360° simplified the machining and produced a trivial reduction in cost.

5. Mounting Block--This was a change in material for the part from 403 monel to 70/30 cupronickel--a minor cost saving. A benefit to using cupronickel is no processing such as plating required before use as required with monel.

6. Waveguide Stiffener--Used to prevent deformation of the soft copper waveguides under atmospheric pressure, the stiffeners, see Figure 13, were changed from stainless steel to

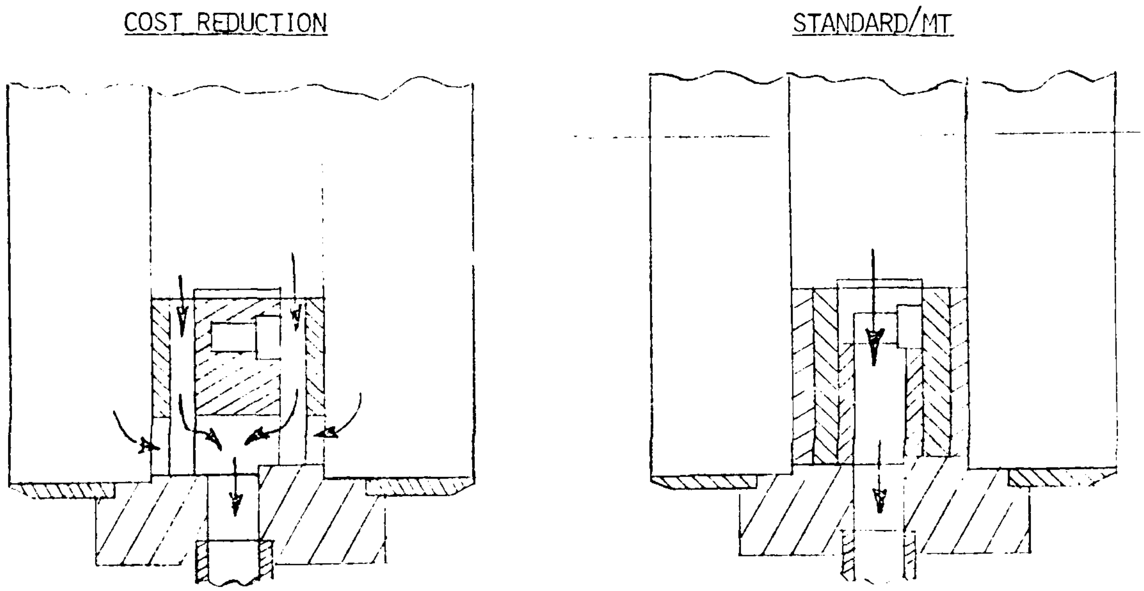


FIGURE 11

EXHAUST ARRANGEMENT

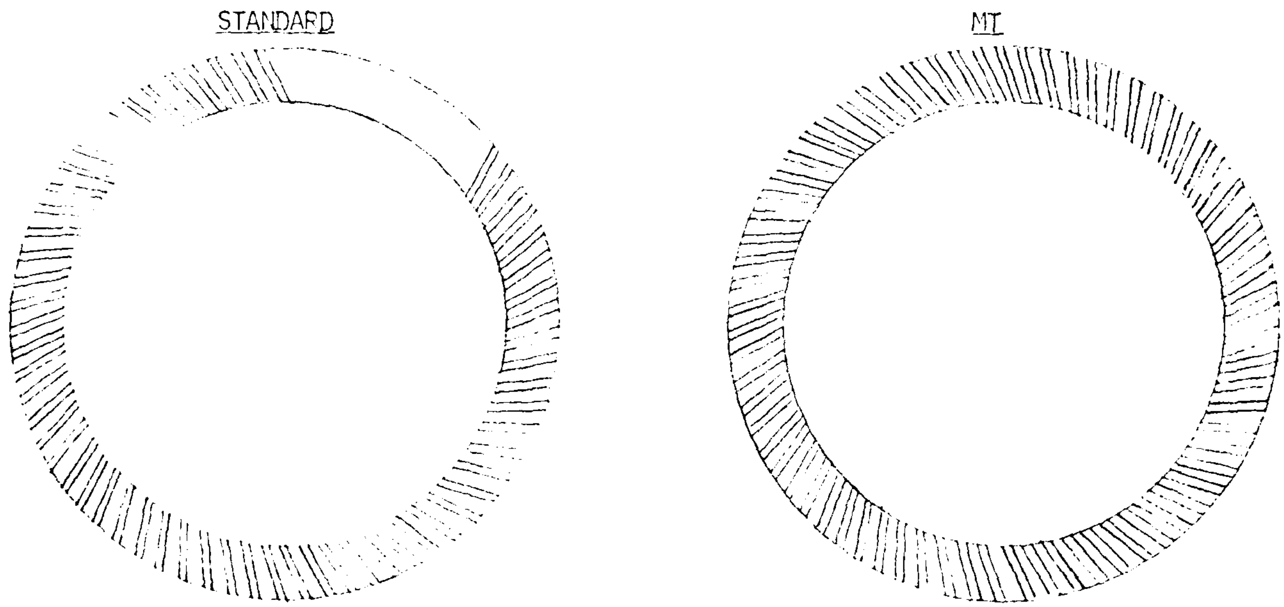


FIGURE 12

HELIX MACHINING

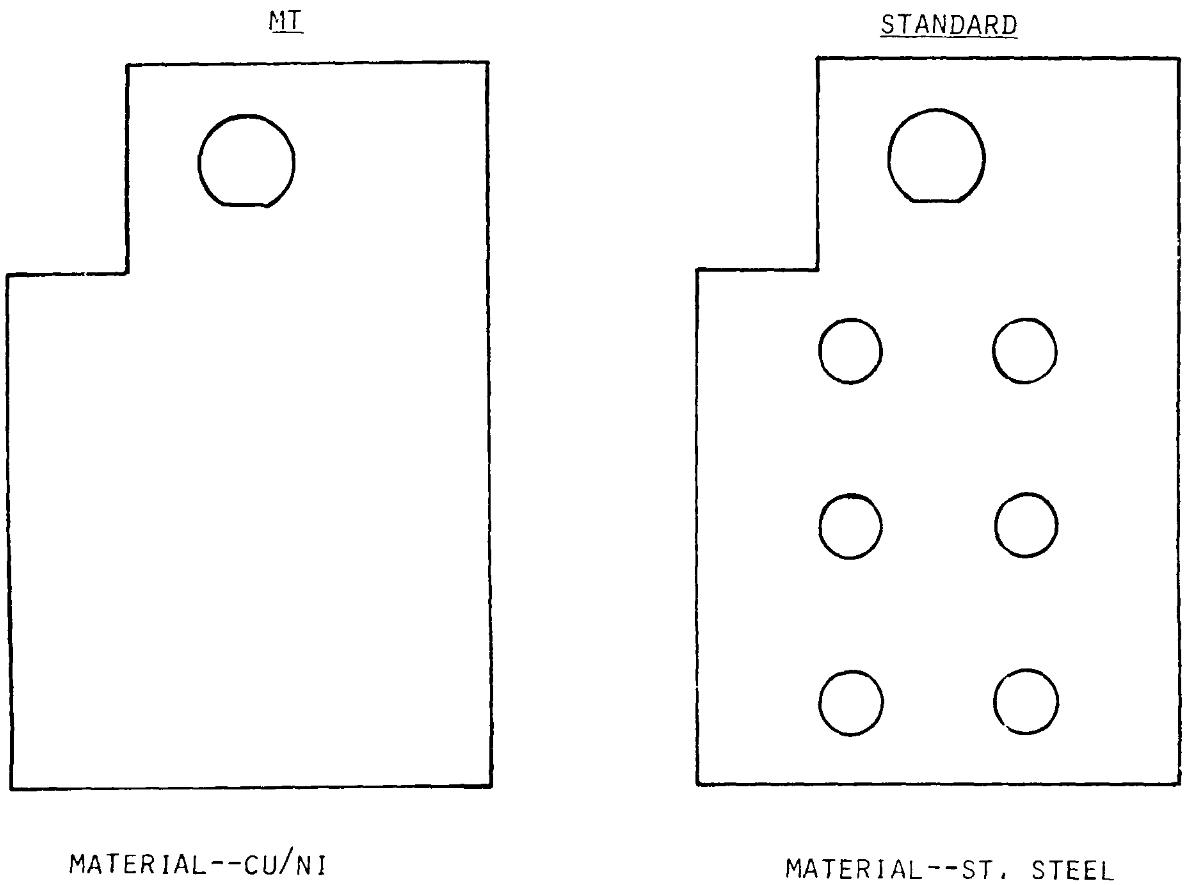


FIGURE 13

WAVEGUIDE STIFFENER

cupronickel and six holes were eliminated--a minor cost reduction.

7. Forged Transformer Blank--The input/output waveguide transformer design was changed from an assembly of many parts to a few, and the transformer section itself was produced by N/C machining techniques. A further cost reduction was considered. Instead of machining the transformer from a solid blank, an attempt was made to forge a blank which would reduce machining time. The price quoted from the vendor was twice his earlier estimate and it did not prove to be cost effective. See Figure 14.

8. Pre-Metallized Ceramics--In addition to buying the input and output window ceramics premetallized, consideration was also given to changing the material from 99.5% pure aluminum oxide (alumina) to 94% pure. The lower purity material is considerably easier to metallize. A decision was made to purchase the windows pre-metallized, but not to change the material. Figure 15 compares the properties of 99.5% pure to 94% pure alumina. The lower purity material is weaker both in compression and tension, has half the thermal conductivity, and a dissipation factor five times higher than 99.5% pure alumina. A survey of the Beverly site's use of the two materials showed the lower purity being used only at X and Ku-band where average power levels are modest. At C-band and S-band, however, only 99.5% pure alumina was used.

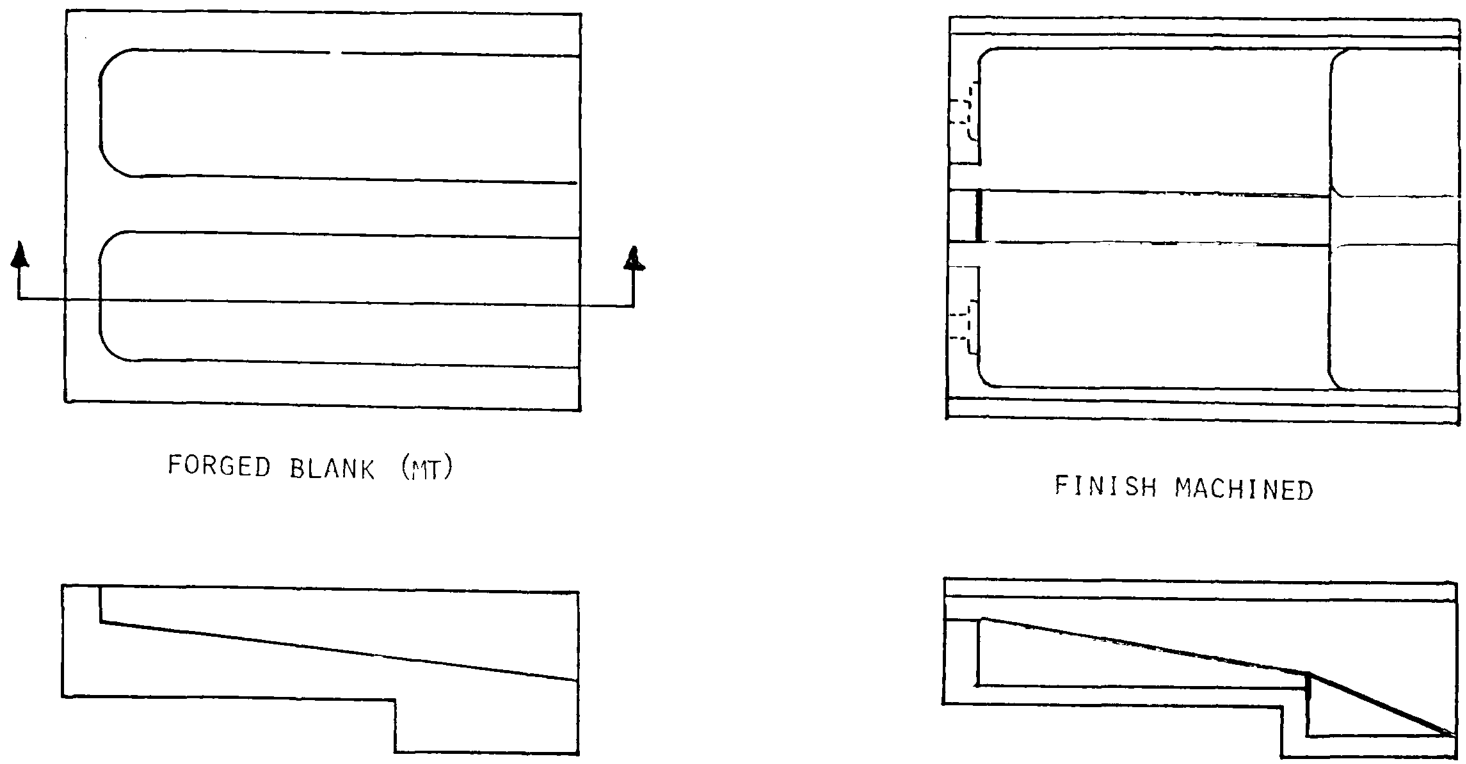


FIGURE 14--TRANSFORMER

	99.5% PURE ALUMINA	94% PURE ALUMINA
HARDNESS (ROCKWELL 45N)	83	78
COMPRESSIVE STRENGTH (KPSI)	380	305
TENSILE STRENGTH (KPSI)	38	28
THERMAL CONDUCTIVITY (BRITISH)		
AT 68 F	20.6	10.4
752 F	7.0	4.6
1472 F	3.6	2.9
DIELECTRIC CONSTANT (10 GHZ)	9.7	8.9
DISSIPATION FACTOR (10 GHZ)	0.0002	0.0010
CURRENT USE AT VARIAN	ALL OTHERS	250 KW LINE AT X-BAND ALL KU-BAND BUT ONE TYPE

FIGURE 15

COMPARISON OF WINDOW CERAMICS

9. Window Block--The window block design has been simplified to eliminate 3 drilling operations on the piece part as well as incorporating finished dimensions to eliminate a final machining operation on the window assembly. See Figure 16.

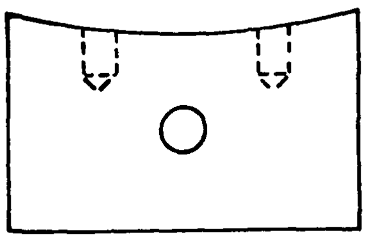
10. Window Waveguide Adapter--The MT design eliminates an expensive reoperation machining procedure and chemical cleaning process prior to its use in the next higher level assembly operation; thus also eliminating a logistic and handling problem from assembly area, machine shop, chemical process area and back to the assembly area. A portion of the adapter also includes the first matching step of the transformer which has allowed the redesign and simplification of the transformer assembly which has been extremely cost effective. See Figure 17.

11. Window Flange--The window flange on the MT configuration is purchased as a finished machined part rather than in blank form as on the standard design. See Figure 18.

By purchasing the piece part in a final machined state it has eliminated a costly machining operation as required on the standard design and has proven cost effective by eliminating another logistics and handling problem. It has also removed another machining operation that from time to time could result in scrapping of the assembly thru operator error.

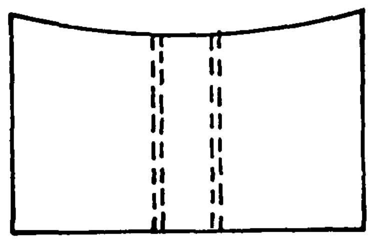
12. Window Housing Vent Hole--A minor cost effective change in the window housing was accomplished by reducing the number of close tolerance vent holes from two to one, and changing the diameter

STANDARD



REQUIRES ADDITIONAL
MACHINING OPERATION

MT



REQUIRES NO ADDITIONAL
MACHINING OPERATION

FIGURE 16

WINDOW BLOCK

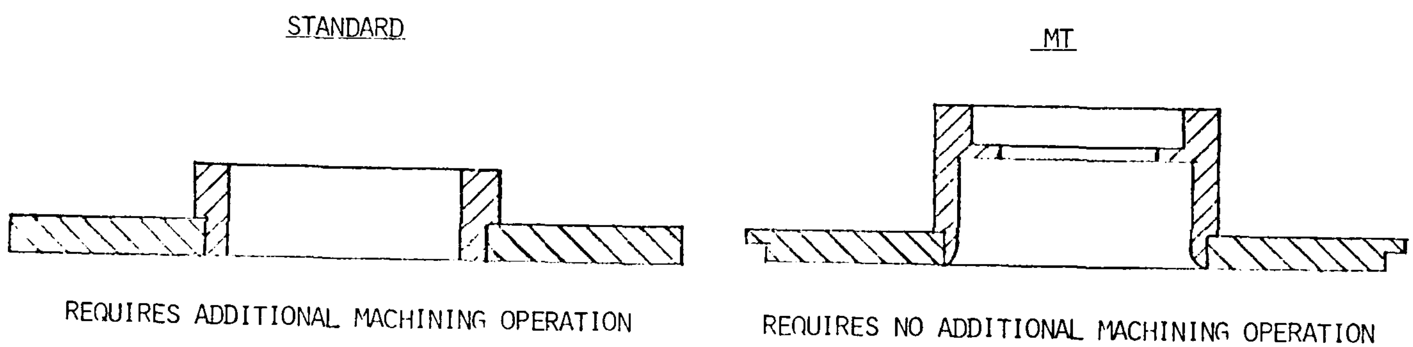


FIGURE 17

WINDOW WAVEGUIDE ADAPTER

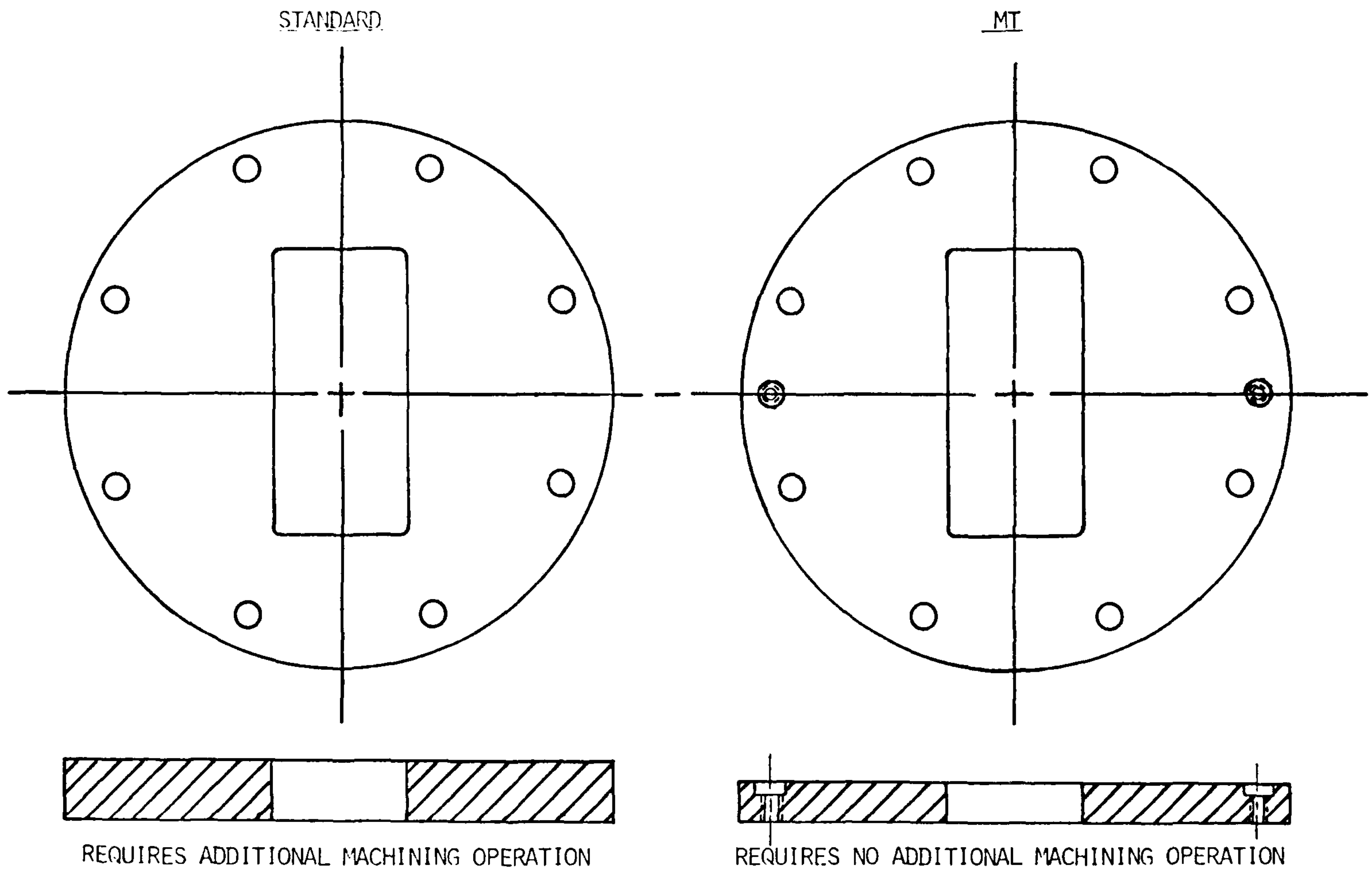


FIGURE 18--WINDOW FLANGE

of the hole to lesser diameter and tolerance. See Figure 19. This vent hole is only used during the initial brazing operation to assure access of the hydrogen atmosphere acting as a flux to penetrate into a brazing region to enable a clean and vacuum tight braze.

14. Cathode Support--With the MT cathode designed for a single vacuum braze and one machining operation, the cathode support was redesigned from a blank support as incorporated in the standard design to a finished machined part to accept both cathode matrix and end hats. Although the piece part is slightly more expensive than the stamped design, the subsequent handling of reoperation machining and cleaning of the assembly is much more costly than the MT design.

15. Cathode Construction--The resdesigning of the cathode structure with emphasis on fewer and less complex piece parts requiring less reoperations in assembly, machine shop and brazing has proven one of the most cost-effective areas accomplished on this program. See Figure 20. The overall cost of this assembly has been reduced by almost 70% over the standard design.

With the MT cathode configuration requiring only one vacuum braze rather than the 4 as found in the standard design, approximately 10 hours of expensive vacuum equipment usage time has been eliminated.

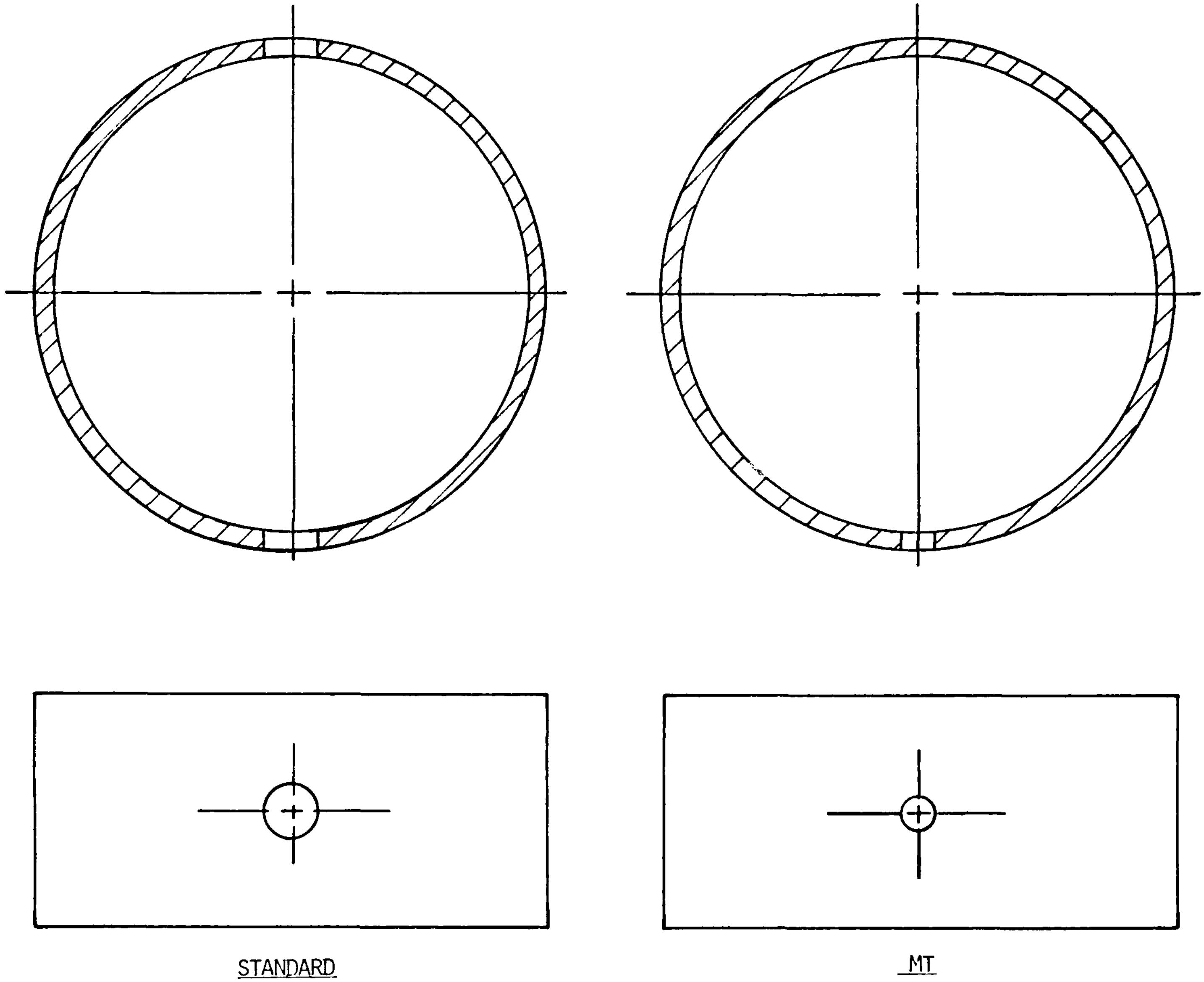


Figure 19--Window Housing Vent Hole

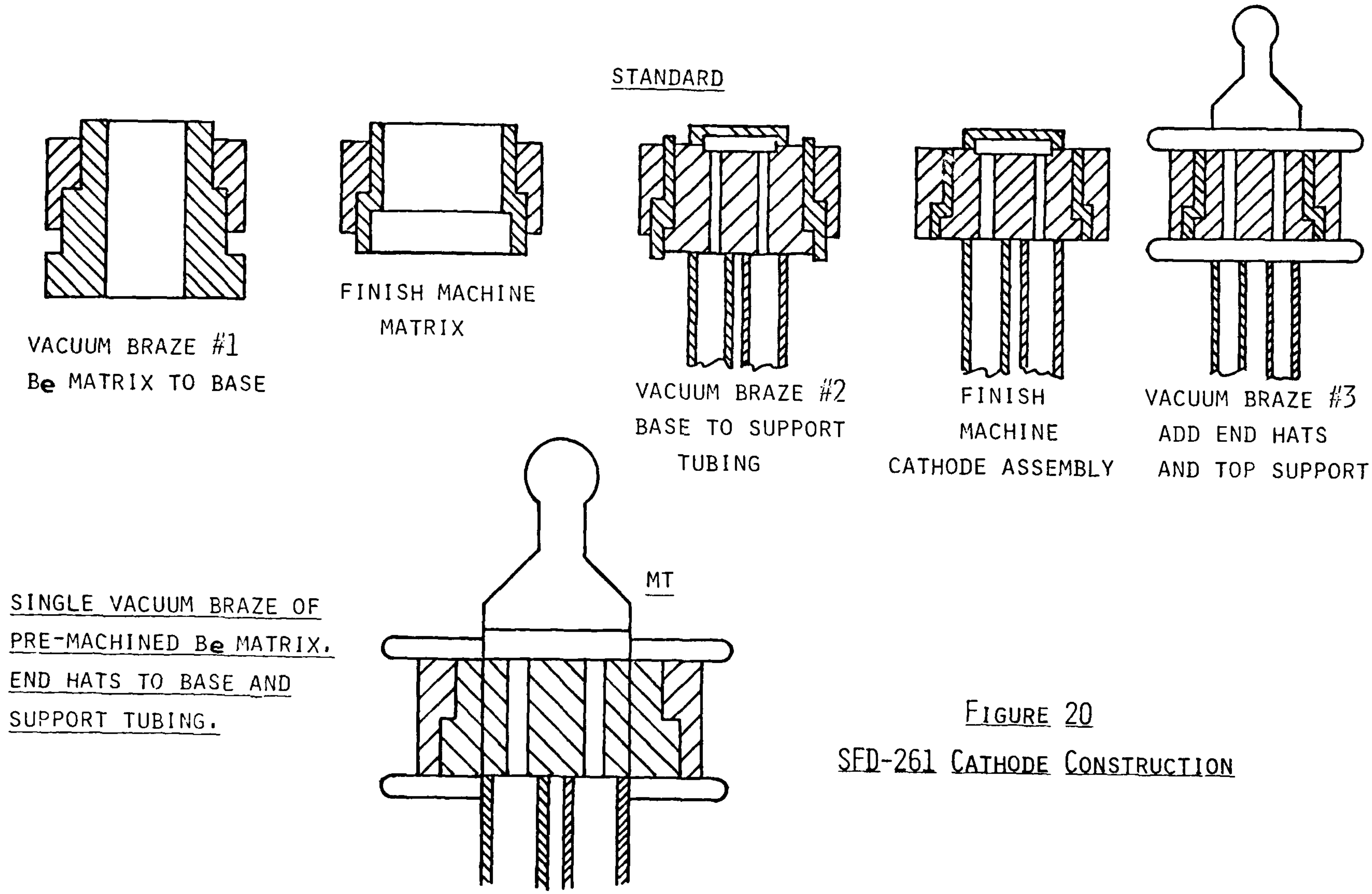


FIGURE 20

SFD-261 CATHODE CONSTRUCTION

The following table illustrates the various areas of accomplishment.

Requirements	Std. SFD-261	SFD-261 MT
Piece Parts	27	10
Hydrogen Brazes	3	1
Vacuum Brazes	4	1
Machining Operations	6	1

16. Cathode Support Cylinder--The MT design of the cathode support cylinder was very cost effective as it eliminated the need of an additional 3 piece parts as required and 1 subsequent reoperation machining. See Figure 21. The piece part itself eliminated a secondary machining operation of drilling 4 viewing holes that were a carry-over from the original D.C. tube design.

17. Cathode Tolerances--The overall height of the cathode matrix tolerances on the MT tube were increased to a ±002 from +000,-001 tolerance on the standard design. This served a twofold purpose. It decreased the unit piece part cost by allowing for looser tolerances, and at the same time increased the suppliers yield consequently reducting his cost of scrapped parts.

18. Cast Heliarc Rings--The intent of this change was to reduce machining time by casting a blank from which the part would be machined. See Figure 22. The castings, in the relatively small quantities to be used, were too expensive. The part is now N/C machined from a stock blank.

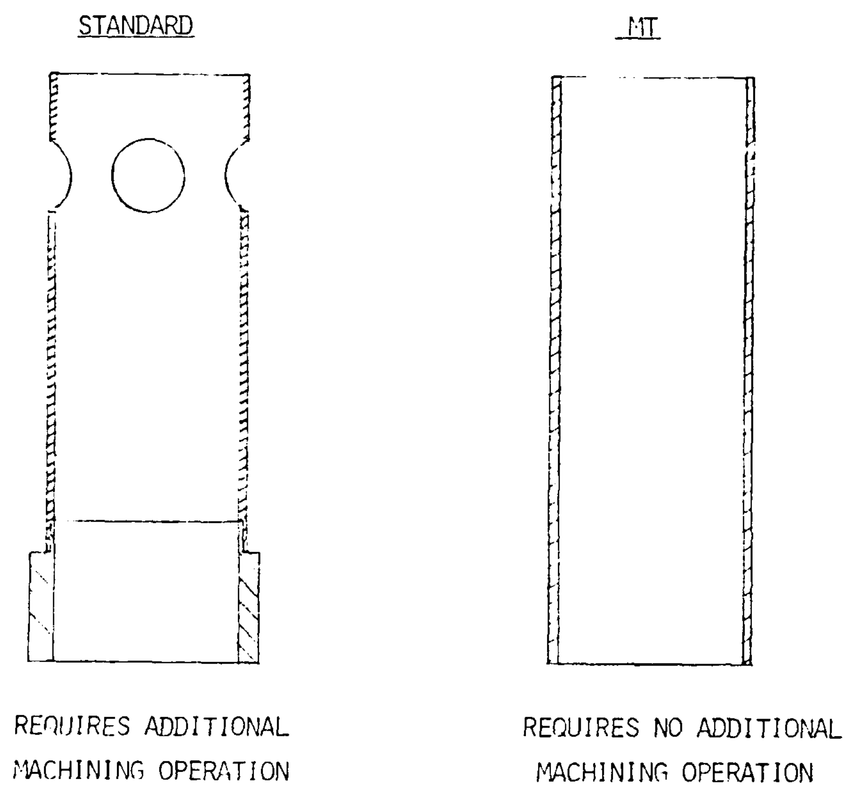


FIGURE 21

CATHODE SUPPORT CYLINDER

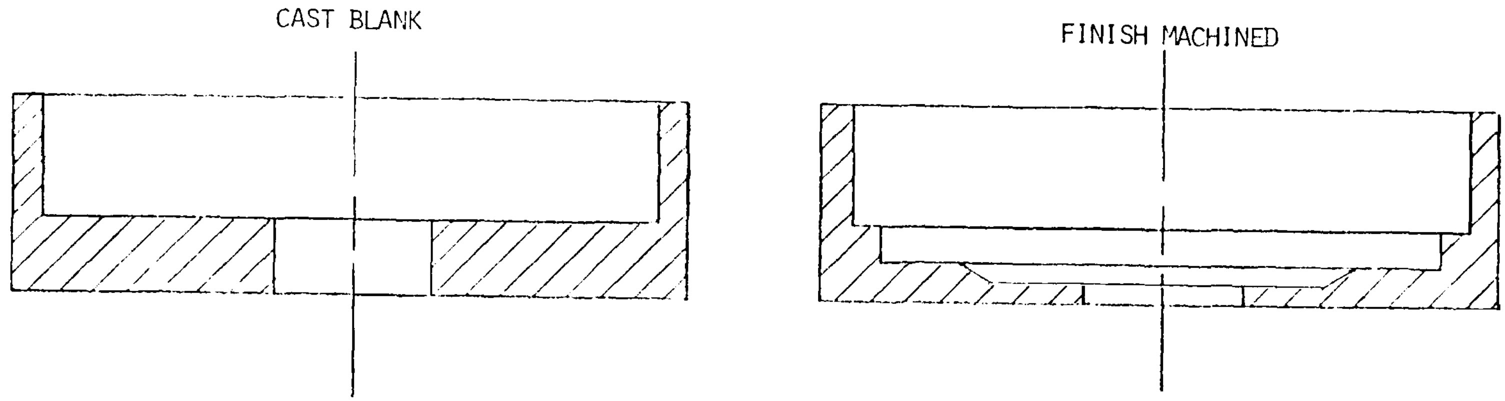


FIGURE 22--HELIARC RING

19. Magnetic Can--This is the cylindrical housing around the body-waveguide assembly which is also the return path for the magnetic field. Now fabricated from steel tubing, an attempt was made to have the can rolled from flat stock. We could not find a vendor who would respond to the small quantities we needed.

20. Cathode Support--The redesign of the ceramic cathode support has proven cost effective by eliminating a very tight tolerance step grinding operation to increase the voltage breakdown path, by simply grinding in a radius that will approximate the length of the step ground stand and configuration. See Figure 23.

21. Bellows--Proposed a material change to stainless steel from monel, but brazing problems with the stainless bellows forced a return to monel. No cost improvement.

22. Support Retainer--The material for this part was changed from monel to cupro-nickel to make a minor cost reduction.

23. Top Pole Piece Construction--Consideration was given to a redesign of this assembly to relieve some of the precision which is built into it. Results of the Vane Tip Investigation (a Raytheon/Wayland-supported program) which was proceeding in parallel suggested that cathode position has a strong influence on localized dissipation (possibly leading to melted vane tips) and it was decided that improved precision in the top pole piece rather than relief of precision was called for. For the present, the design was not changed.

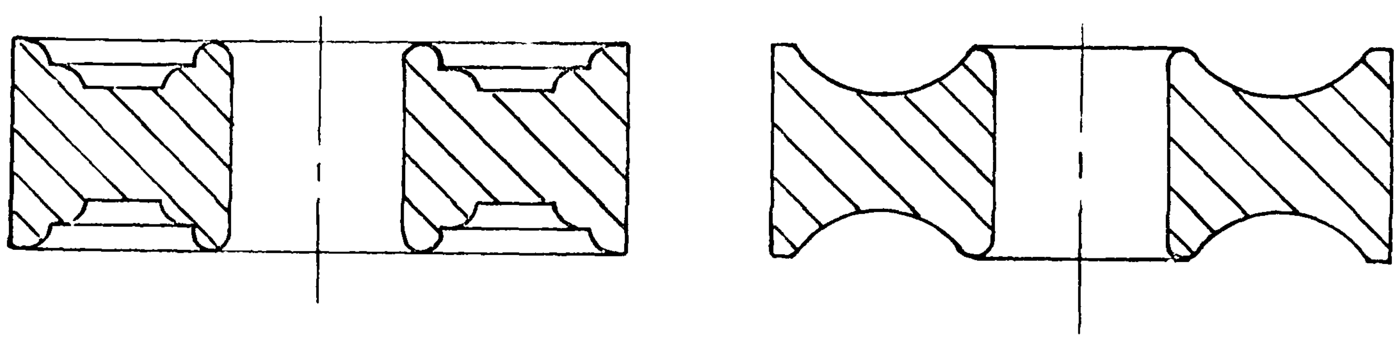


FIGURE 23--CATHODE SUPPORT

24. Stamped Mounting Plate--As with previous efforts to use stampings, castings, or forgings, the quantities were too small to justify making a stamped blank as in Figure 24.

25. Support Mounting Plate--This part, shown in Figure 25, was made from a cast blank rather than solid stock. It is pressed and pinned to the mounting plate. One vendor was unexpectedly responsive to this request by comparison with our other attempts to use forgings, castings and stampings.

26. Tubing Support--A double coil of high pressure nylon tubing is used in the standard design to provide an insulating column of coolant between the high voltage of the cathode and the ground potential of the mounting plate through which the coolant passes. The assembly of this coil has been a tedious task requiring the threading of the relatively stiff nylon tubing thru the several supports which are used. The MT change eliminates the threading and permits the tubing to be snapped into place. These supports play only a temporary mechanical role because the tubing assembly is later encapsulated in a silicone potting which provides most of the mechanical support for the assembly. See Figure 26.

27. High Voltage Can End--The silicone encapsulated high voltage end of the tube is further protected by a metal enclosure. In the standard design the enclosure was made with a cylinder and an end plate which were fastened to the mounting plate and each other with 24 screws in blind tapped holes. These

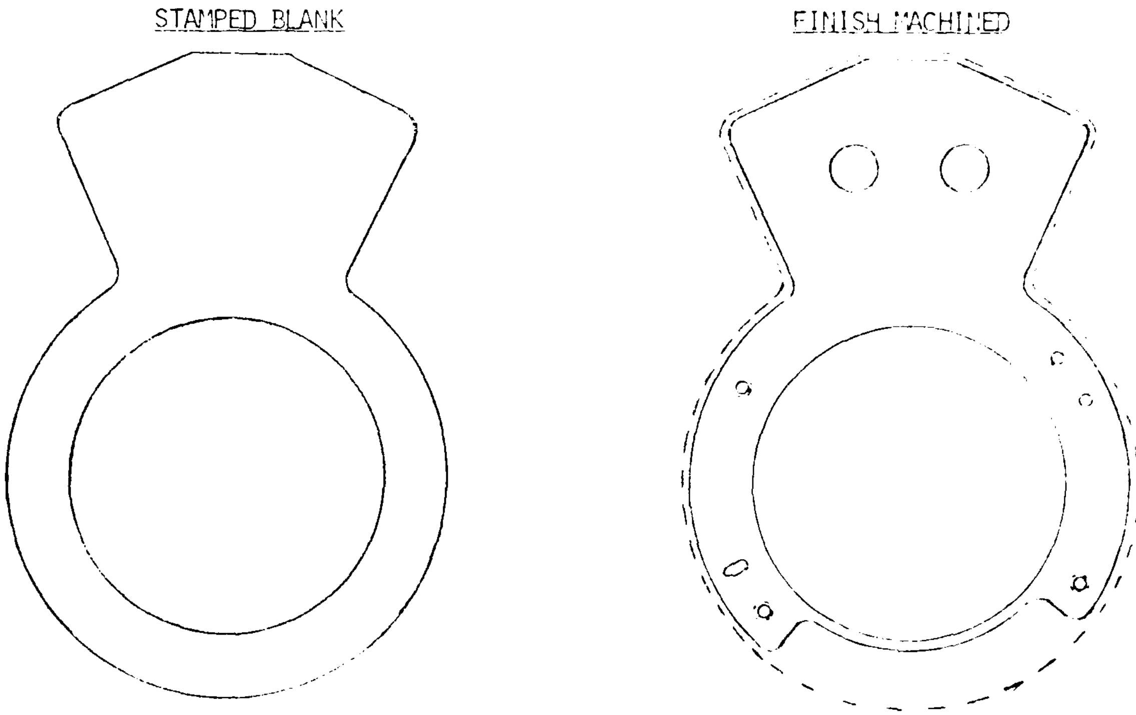


FIGURE 24

MOUNTING PLATE

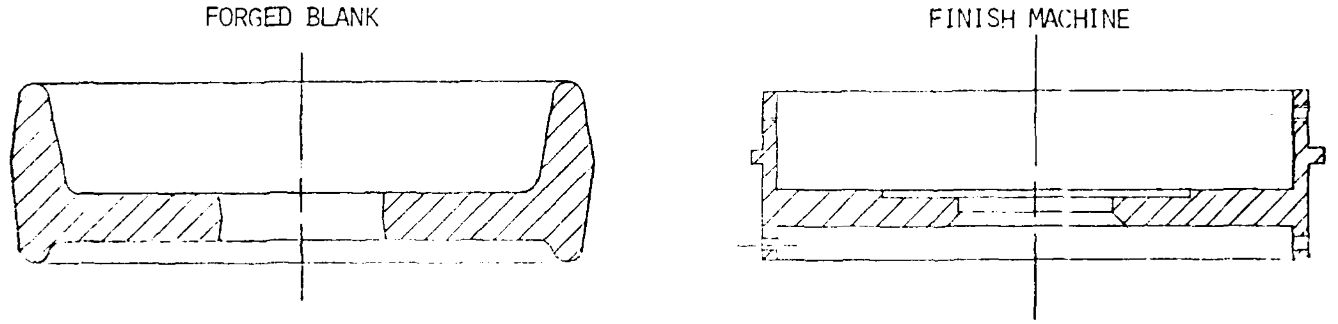


FIGURE 25

SUPPORT PLATE

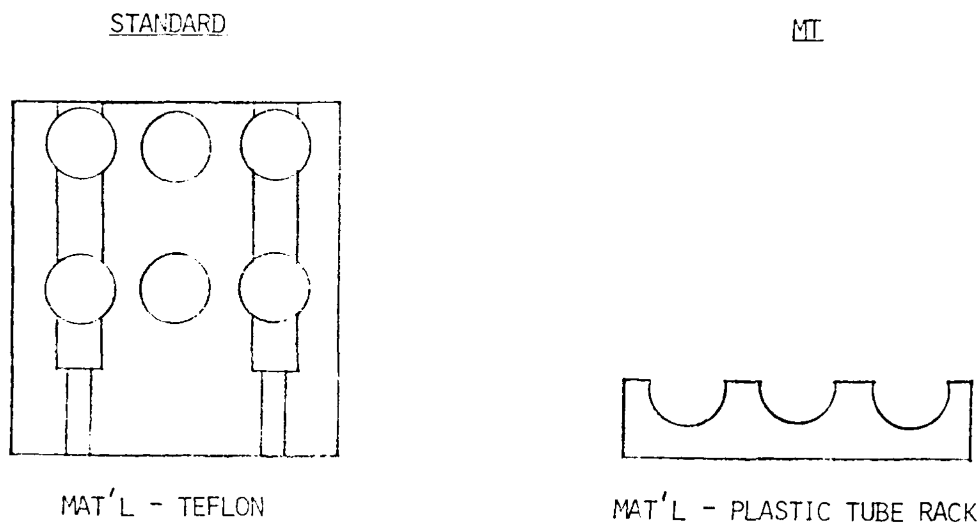


FIGURE 26

TUBING SUPPORT

were replaced by a single hydroformed can attached to an extension of the mounting plate with 8 Pop® rivets (rivets which are inserted and set from the same side of the work). See Figure 27.

28. Top Plate--The top plate is part of the magnetic circuit connecting the ends of the magnets via the cylindrical shell. The thickness tolerance was made larger so that stock material could be used instead of machining it down from larger plate thickness.

29. Magnet Tolerances--Relief was provided in several areas to reduce the precision of the machining operations.

30. Two Liter Pump*--The CFA is equipped with an integral 0.2 liter ion pump, but also has a 2 liter appendage pump which is removed from the CFA during manufacturing. The object of using a second and larger pump is to provide a repository for all gases removed from the tube during the initial aging and processing of the tube without using up any of the capacity of the 0.2 liter integral ion pump. This objective was considered important, and, because the 2 liter pump is reused a number of times, the cost savings resulting are not a significant trade-off for the objective.

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*Nominal pumping speed of 2 liters per second.

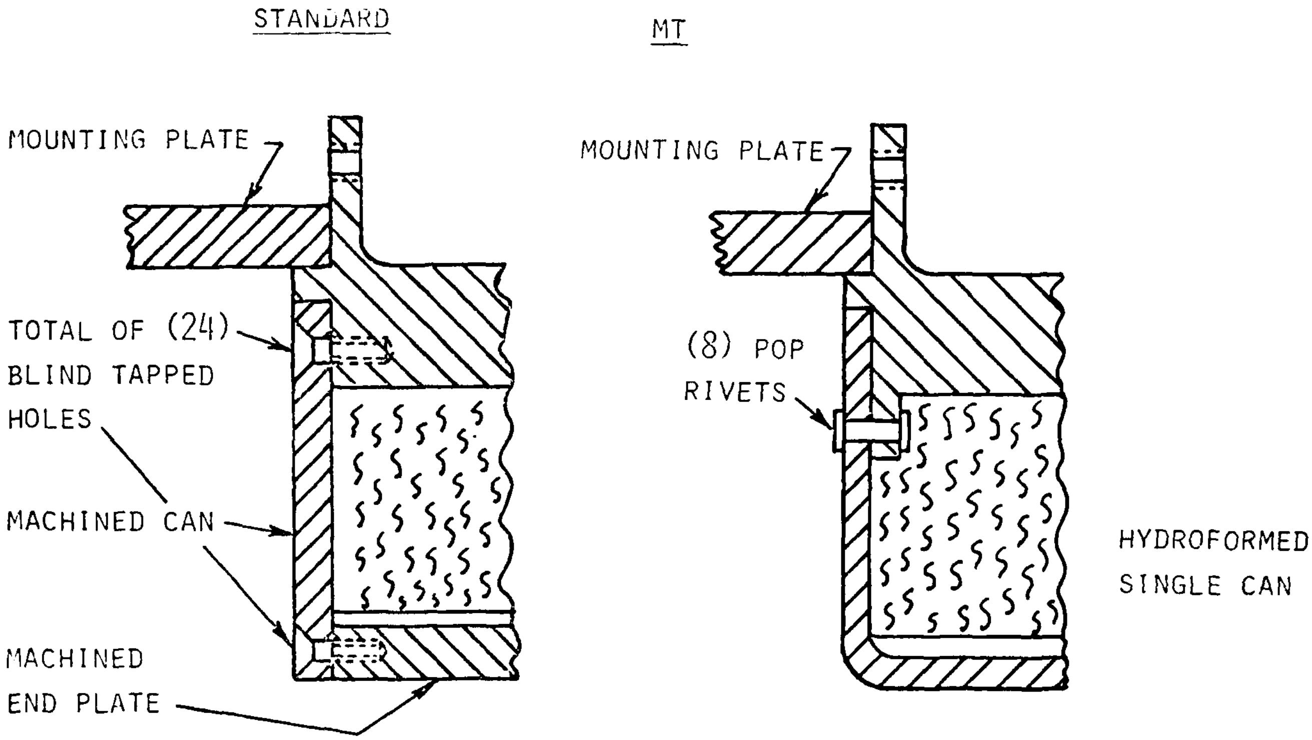

FIGURE 27

SFD-261 HIGH VOLTAGE CAN END

3.0 NOISE IMPROVEMENT PROGRAM

Another difference which was introduced into the MT tube is the structure known as the skimmer or beam scraper. The skimmer or beam scraper was developed and tested on a Navy-sponsored noise improvement program under contract No. N00024-76-C-5102.* Under this contract, experiments showed a possible 3 to 5 dB improvement in noise performance with the incorporation of the skimmer. The skimmer is a geometric perturbation between the RF output and the RF input of the CFA--a region also known as the drift region. The object of the skimmer geometry is to keep space charge from approaching the slow wave circuit at the input portion of the tube. If the electron stream can be kept a distance from the slow wave circuit, the magnitude of noise currents induced on the circuit will be reduced. As will be described in Section 7.0, the results obtained on the MT program were beneficial, but not as good as expected.

*Naval Sea Systems Command, Washington, D.C.

4.0 VANE TIP IMPROVEMENT PROGRAM

One of the principal cost drivers of the SFD-261 is the yield which occurs either during manufacture or as field failures in the melted vane failure mode. In this mode the molybdenum vane tip on the slow wave circuit near the output becomes separated from the heat sink, melts, and causes a CFA failure which is basically not repairable. Without becoming involved in the details of the reasons for failure, it is sufficient to recognize that this mode of failure accounts for one of the largest percentages of the overall shrinkage in the tube manufacture. It is also possible that it will be the cause of the highest number of field failures unless the problem is addressed.

In August 1978, a subcontract was placed with Varian by the Raytheon Company, Equipment Development Laboratories, in Wayland, Massachusetts (subcontract No. 53D-064-EX-95000). The purpose of this program was to investigate the vane tip failure mode and to conduct an experimental program to evaluate corrective measures. Unfortunately, commitments had already been made for material on the MT program and none of the improvements appeared in time for incorporation into the MT program. It is felt, however, that future production quantities using the MT design could benefit from some of the improved processes and procedures which were worked out under the Raytheon vane tip investigation.

5.0 THE SILASTIC PROBLEM

A report prepared in April 1979 discussing the Silastic failure problem is attached as Appendix 1. The appearance of this failure mode in the summer of 1978 eventually caused several months delay in the MT program until a satisfactory remedy could be found. While the delay was undesireable because it postponed the introduction of the MT design into the shipbuilding program, it was necessary to prevent clouding the results of the MT program's tubes with a non-MT-related failure mode.

6.0 PHASE MEASUREMENT PROBLEMS

Each CFA produced has a variety of phase measurements made on it using a phase bridge. The phase bridge is the combination of a commercial instrument with other commerically available components such as line stretchers. Together they make up a phase measuring system with which a comparison can be made and plotted of the phase difference between the RF input signal and the RF output signal as a function of frequency. Beginning as far back as September 1978, certain anomalies began to appear in the phase measurement system. By January 1979, it appeared that no consistent phase measurement could be made with the existing equipment. Therefore, at the end of January the phase measuring equipment was sent out for repair and recalibration. From January until April it was not possible to make phase measurements, and the delivery of tubes was being delayed on that account. A phase bridge of a different kind was loaned to Varian by the Raytheon Company, and that was put into service in April. When the original piece of Varian equipment was repaired and returned to us, a consolidation of phase measurement procedures was made such that the measurements made on either the Raytheon-furnished bridge or the Varian equipment could be equated.

The result was an improved phase measurement procedure, but also that shipment of many tubes had been delayed for significant amount of time. These included some of the MT tubes.

7.0 COMPARISON OF SFD-261 MT NOISE AND POWER PERFORMANCE

A tabulation has been made comparing performance parameters such as power output, intrapulse noise, efficiency, oxygen reservoir voltage, oxygen reservoir current, spurious output levels, and coolant pressure drop for a sample of the SFD-261H lead ship tubes versus the sample of SFD-261 MT tubes. The tabulation is shown in Table III. The lead ship sample consisted of 26 tubes and the MT sample consisted of 10 tubes. The frequency labels are coded and no other units are shown in order to leave the table unclassified.

With respect to power output, one can see quickly that there is a very close similarity between the two tubes. With respect to intrapulse noise, the similarity is preserved up through F3, above which at F4 and F5 the MT tube shows somewhere between a 2 and 3 dB improvement over lead ship designs. No significant differences are seen in efficiency, oxygen reservoir voltage, oxygen reservoir current, and a small improvement is shown in spurious output level. The coolant pressure drop, as expected, is not changed appreciably. The equivalence of the two designs is easily seen from this tabulation.

A more detailed comparison not only with lead ship tubes but also with EDM-1 tubes is shown in Figure 28. Figure 28A shows the data from Table III plotted with data from an EDM-1 sample of 10 tubes also plotted for comparison. Figure 28A shows the graphical comparison of output power as a function of frequency,

	L.S.	MT	L.S.	MT	L.S.	MT	L.S.	MT	L.S.	MT
	f_1		f_2		f_3		f_4		f_5	
Power	1154	1159	1217	1224	1255	1255	1277	1261	1280	1256
Noise	52.0	52.6	52.4	52.3	52.3	52.7	48.7	49.9	46.5	49.0
Efficiency	49.1	50.5	52.6	53.2	54.8	54.7	56.2	55.5	56.8	55.5
V_{RES}	5.13	5.10								
I_{RES}	1.07	1.04								
Spurious	45.8	48.9								
Pressure Drop	13.8	12.3								

MEAN PERFORMANCE VALUES

SFD-261H LEAD SHIP (L.S.) VERSUS SFD-261 MT

Lead Ship Sample	26 Tubes
MT Sample	10 Tubes

TABLE III

FIGURE 28--COMPARISON OF MT TUBE POWER OUTPUT AND EFFICIENCY WITH LEAD SHIP AND EDM-1 TUBES

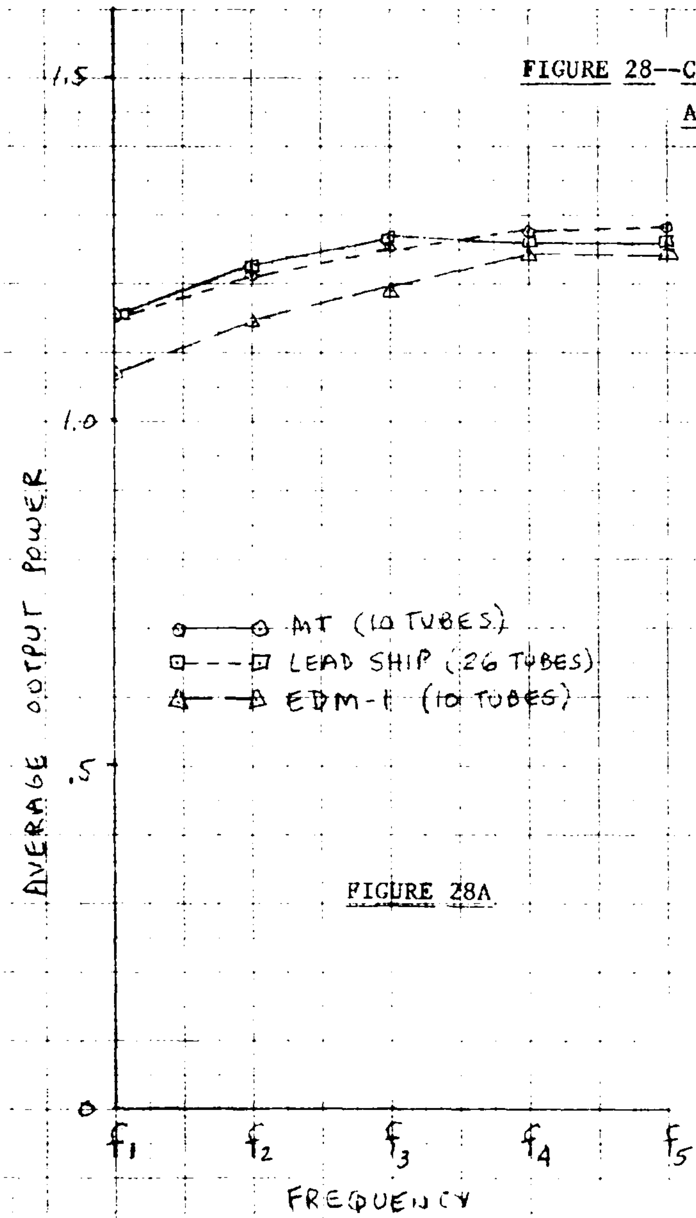

FIGURE 28A

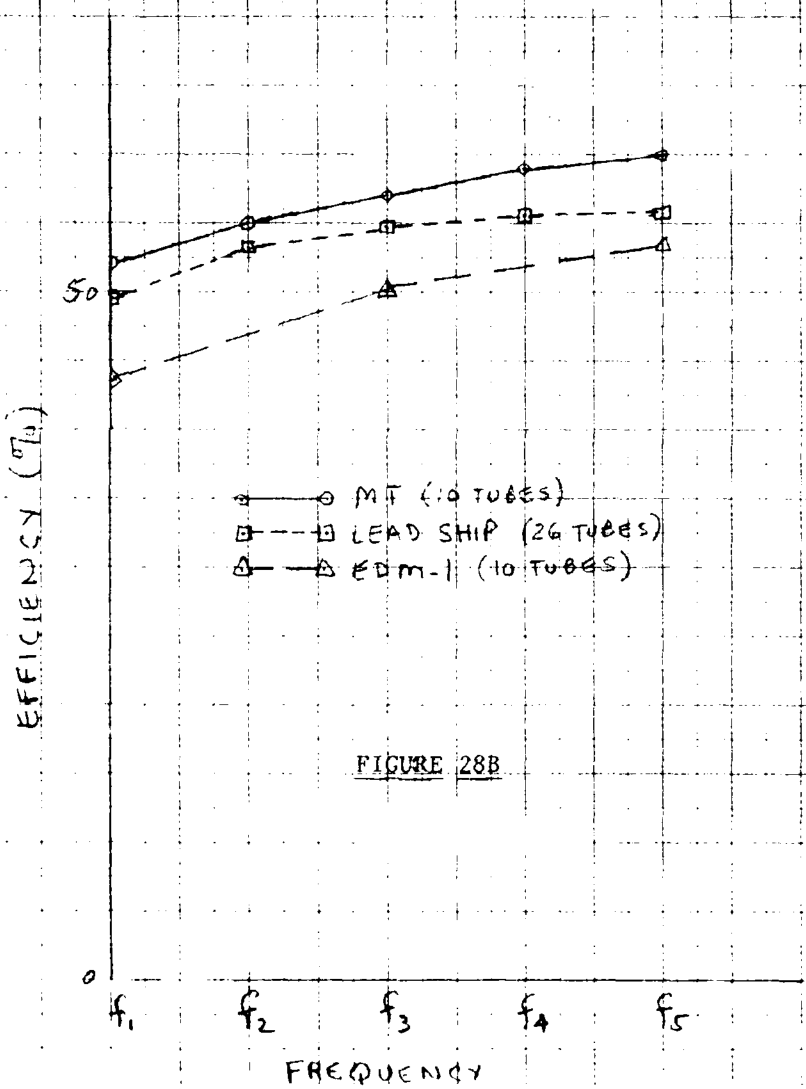

FIGURE 28B

and Figure 28B shows efficiency as a function of frequency. In either case, the MT design is shown to be similar to or better than either of the lead ship or EDM-1 samples. Figure 29 shows a similar comparison for intrapulse noise as a function of frequency. In this graph, as in Table III, one can see that at the high frequency end of the band a small improvement is observed from the MT sample of tubes.

Perhaps the most significant difference which can be found between the MT tube sample and the lead ship sample is in the phase performance as a function of frequency. In particular, the phase length of the MT tube seems to be substantially different from the length of the lead ship tubes. The reason for this is in the difference in the slow wave circuit to waveguide matching structures. In Table IV is shown a tabulation of each of the 11 MT tubes in degrees per GHz at F1. Also shown in the table is the mean phase length for a sample of lead ship tubes which make up the lead ship phase standard. This phase length is shown at the bottom of the tabulation. There is a difference in phase length of 11.7°/GHz at F1 between the two tube designs. Since the RF power outputs from these tubes are either combined at the output of the driver/pre-driver stage or are combined in space at the output of the phased array, the phase similarity between the tubes over the frequency band is of importance. It must be possible to make phase adjustments in the system so that the phase length of tubes track within certain tolerances as they are swept over the frequency band. A discussion on this and other points follows.

FIGURE 29

COMPARISON OF MT TUBE INTRAPULSE NOISE WITH LEAD SHIP AND EDM-1 TUBES

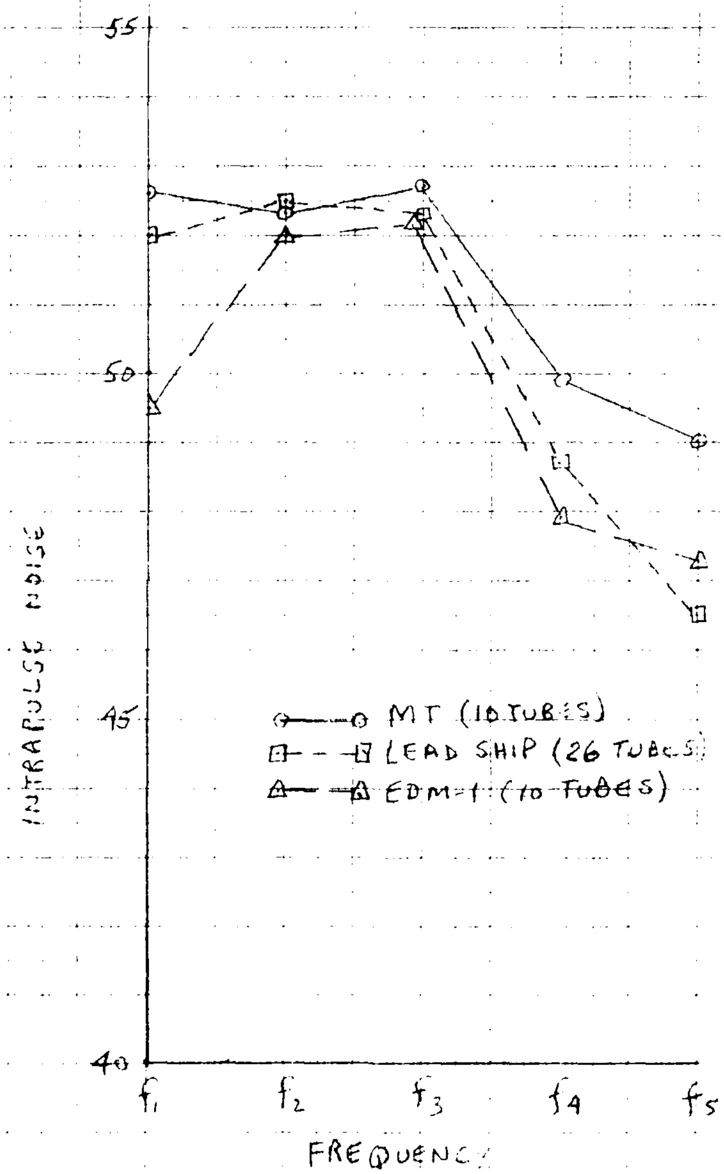

TABLE IV

MEAN PHASE LENGTH OF THE MT TUBE SAMPLE

S/N**	Original Length (°/GHz @ F1)	Zero* Correction (°)	Corrected*** Length (°/GHz @ F1)
B3W	208.0	3	209.0
B102W	197.6	1.7	198.1
K363V	211.8	-3.2	210.8
I343V	207.2	0.1	207.2
I414V	208.9	1.6	209.4
A453W	209.3	-0.8	209.0
K332V	204.3	-3.2	203.3
L74V	210.8	-3.0	209.8
L1V	209.0	-4.0	207.7
K180V	208.8	-1.3	208.4

*Needed to give the phase versus frequency curve a mean of 0.0.

**K185V later added to the list. Not included in standard.

***Mean length of lead ship tubes is 196.2°/GHz @ F1.

When the first cost reduction tubes (CR) were tested in 1974, the differences in performance which were observed between them and the standard SFD-261's were attributed to the different slow wave circuit match which was used in the cost reduction tubes. This match is called the isolated match by Varian (and the matched slow wave circuit by others) and seemed to produce higher output power and efficiency. From this, it was concluded that the matching structure improved the way in which the RF wave was launched onto the slow wave circuit, thereby enhancing the operating efficiency of the tube. This same slow wave circuit match has been introduced into the MT design. That the differences in power output and efficiency are not as apparent in the current comparison may be attributable to the fact that only two cost-reduced tubes were produced, and here we are looking at a sample of 10. The comparison of noise performance between the MT tubes, the lead ship tubes and the EDM-1 tubes shows a little difference in noise performance up to mid band. Above that, however, even with the sample of 10 tubes there is definite improvement in intrapulse noise performance--an improvement level of between 2 and 3 dB at the high frequency end of the band. Since the high frequency end of the band is usually the portion at which the intrapulse noise is worse, this improvement is quite important. The improvement is also less than the 3 to 5 dB which had been expected.

The same slow wave circuit match structure is what accounts for the differences in phase length between the MT tube and the lead ship and EDM-1 tubes (neither of the latter incorporated the matched slow wave circuit). Figure 30 shows a composite of the phase versus frequency characteristic for the sample of MT tubes. Shown in Figure 31 is a similar composite for the lead ship tubes. These are the characteristics which determine the average performance values of the CFA in terms of how they will track with one another over the frequency band. The phase length number is an arbitrary number, but is useful for comparative purposes. The difference between this number for the lead ship group and for the MT group is a real measure of the difference in phase length between the two groups of tubes. In order for the tubes to be mixed in the same transmitter, it is necessary that adequate phase adjustment provision be available to account for the difference in phase lengths. Other than that, the periodic behavior of the phase versus frequency characteristics are not entirely different.

A preliminary indication that there is sufficient phase adjustment available in the equipment lies in the fact that tubes Nos. CR5 and CR6 have operated satisfactorily in the EDM-1 transmitter. This means that there was sufficient phase adjustment available in the transmitter to line the tubes up with the other tubes with which they had to operate. A more formal analysis of

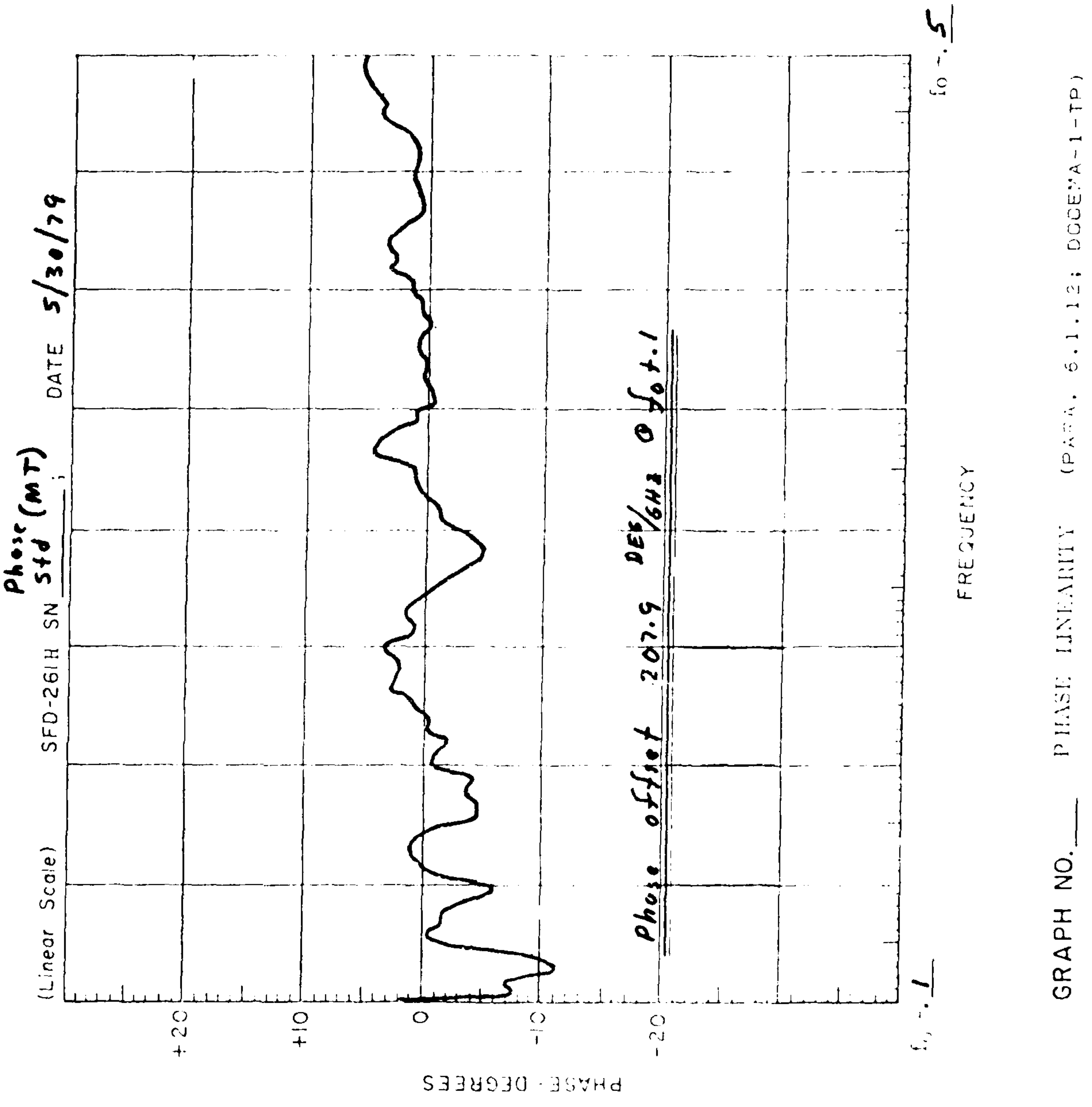

FIGURE 30

MT TUBE PHASE STANDARD

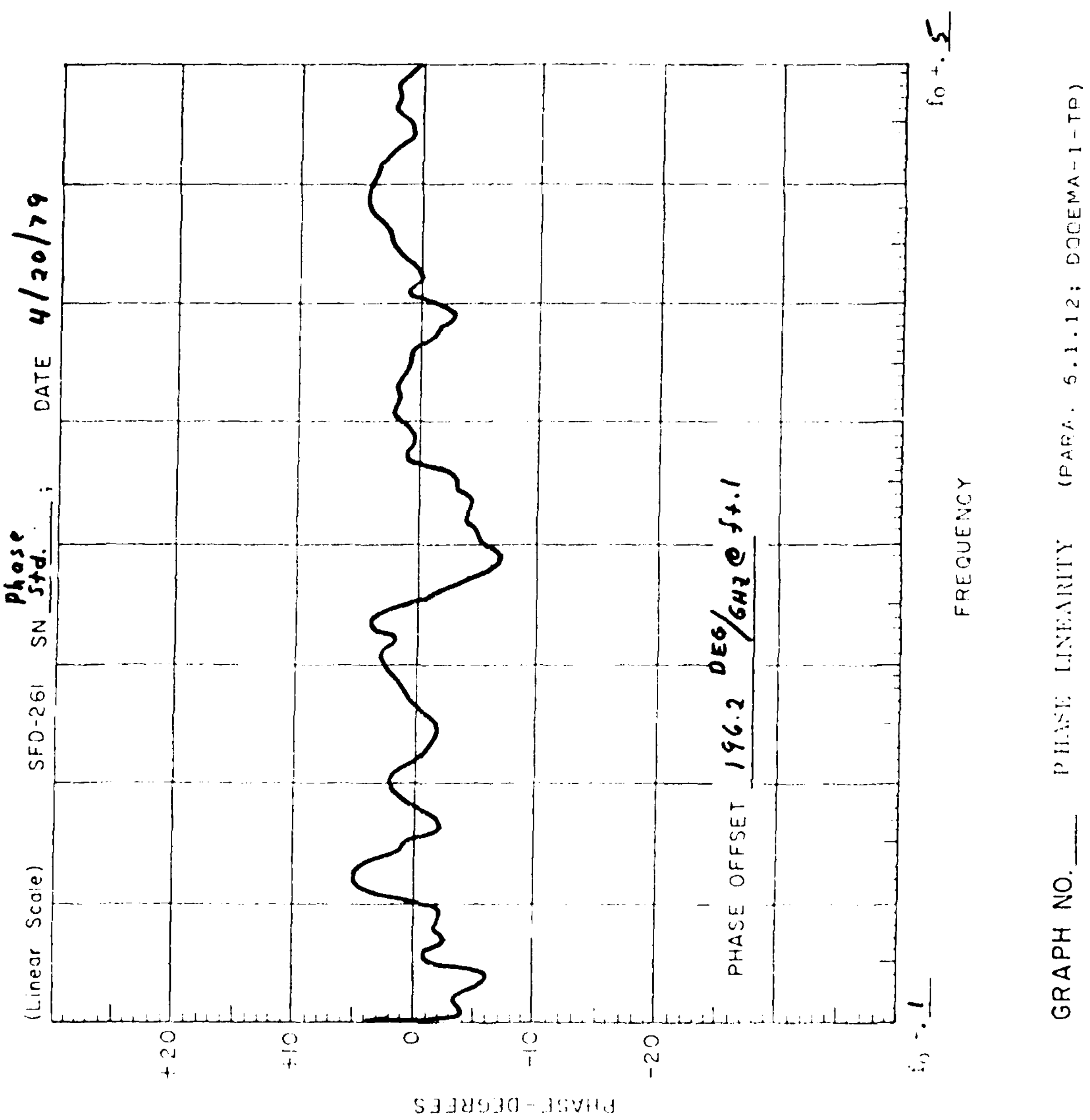

FIGURE 31

LEAD SHIP TUBE PHASE STANDARD

this capability in the system is being conducted presently by the Raytheon Company and RCA. A satisfactory answer to this question is a prerequisite, but not the only one for the use of the MT tube in the Aegis radar system.

Apart from these differences, only a trained eye could tell the difference between an MT tube and a lead ship tube. The form, fit and function have been preserved.

8.0 SUMMARY COST COMPARISON

Details of a cost analysis made from the MT program are to be submitted in a separate cost analysis report. It will be useful, however, to take an overview of the net results of the program on the cost of the SFD-261.

Shown in Table V is an engineering estimate made at the conclusion of the program based upon the procurement of 200 sets of parts of the cost of the standard SFD-261 design, the SFD-261 lead ship design, and the SFD-261 MT design. The standard design is that which was used in the EDM-1 system where tube production took place during the 1971 and 1972 period. A cost reduction program, also sponsored by the Navy, was carried out during 1973 and 1974. That program identified a number of cost reduction measures which were designed into two tubes for evaluation. The cost reduction measures were never subsequently incorporated into a reasonable size sample of tubes in a production environment. During the initial part of the present MT program, a study was made of the various cost reduction measures which had been engineered in 1973-1974. with a view to which would be considered very low risk measures for incorporation into the upcoming lead ship program. A design different from the standard design was, therefore, adopted for lead ship and became known as the SFD-261H (for hybrid). The tube which eventually resulted from the MT program was then identified as the SFD-261MT. Table V makes a comparison between the costs for the standard tube, the lead ship tube, and the MT tube. In terms

TABLE V

ENGINEERING ESTIMATE

MATERIAL COST COMPARISON

(200 Sets of Parts)

	SFD-261 Standard	SFD-261 Lead Ship	SFD-261 MT
Material			
Seal	$ 2,075.55	$ 1,817.63	$ 1,543.72
Final	891.08	869.51	734.21
	$ 2,966.63	$ 2,687.14	$ 2,277.93
Yielded Labor	439 Hrs.	318 Hrs.	245 Hrs.
January 1979 Selling Price	$21,515.00	$15,479.00	$12,205.00

of material it is broken down into seal and final: seal meaning the parts which go into the high vacuum envelope of the tube; and final referring to those external parts sometimes called the magnetic package.

When all of these cost inputs are expressed in January 1979 dollars, the cost reduction is quite apparent from $21,515 for the standard tube down to $12,205 for the MT tube. Obviously, escalation will change these prices, especially with respect to the escalation we are observing on material. But since the escalation would apply no matter which design was manufactured, the cost savings will be real.

9.0 PROPOSED QUALIFICATION PROGRAM

Shown in Figure 32 is a qualification program plan proposed by the Naval Weapon Support Center, Crane, Indiana. Under this plan, the 10 MT tubes would be delivered to NWSC/Crane and 5 of the 10 would immediately be sent to the U.S.S. Norton Sound and/or CSEDS site at RCA/Moorestown.

The remaining five tubes would be partitioned into lots for the different portions of the qualification test program. Two tubes would be assigned to shelf life tests; one of which would undergo a one-year, uninterrupted shelf life test and the other to be interim tested twice during the one-year period. One tube would be submitted to electrical qualification tests in accordance with DOOEMO-1-TP. One tube would be subjected to the environmental system requirements, and one tube would be subjected to an operating life test. After successful completion of the electrical and mechanical qualification testing, the tube lot would be considered to have interim qualification; the final qualification depending upon the outcome of operating life and shelf life tests.

This plan was presented at the End-of-Project demonstration for the MT program which was conducted on May 31, 1979. The group of MT tubes has since been delivered to NWSC/Crane.

As of this writing, all ten tubes have been through electrical testing in accordance with DOOEMA-2-TP. Two tubes, S/N's B3W and I414V, have been selected for life test and have so far accumulated approximately 450 hours. Two other tubes, S/N's B102W and K180V, were

QUALIFICATION PROGRAM PLAN

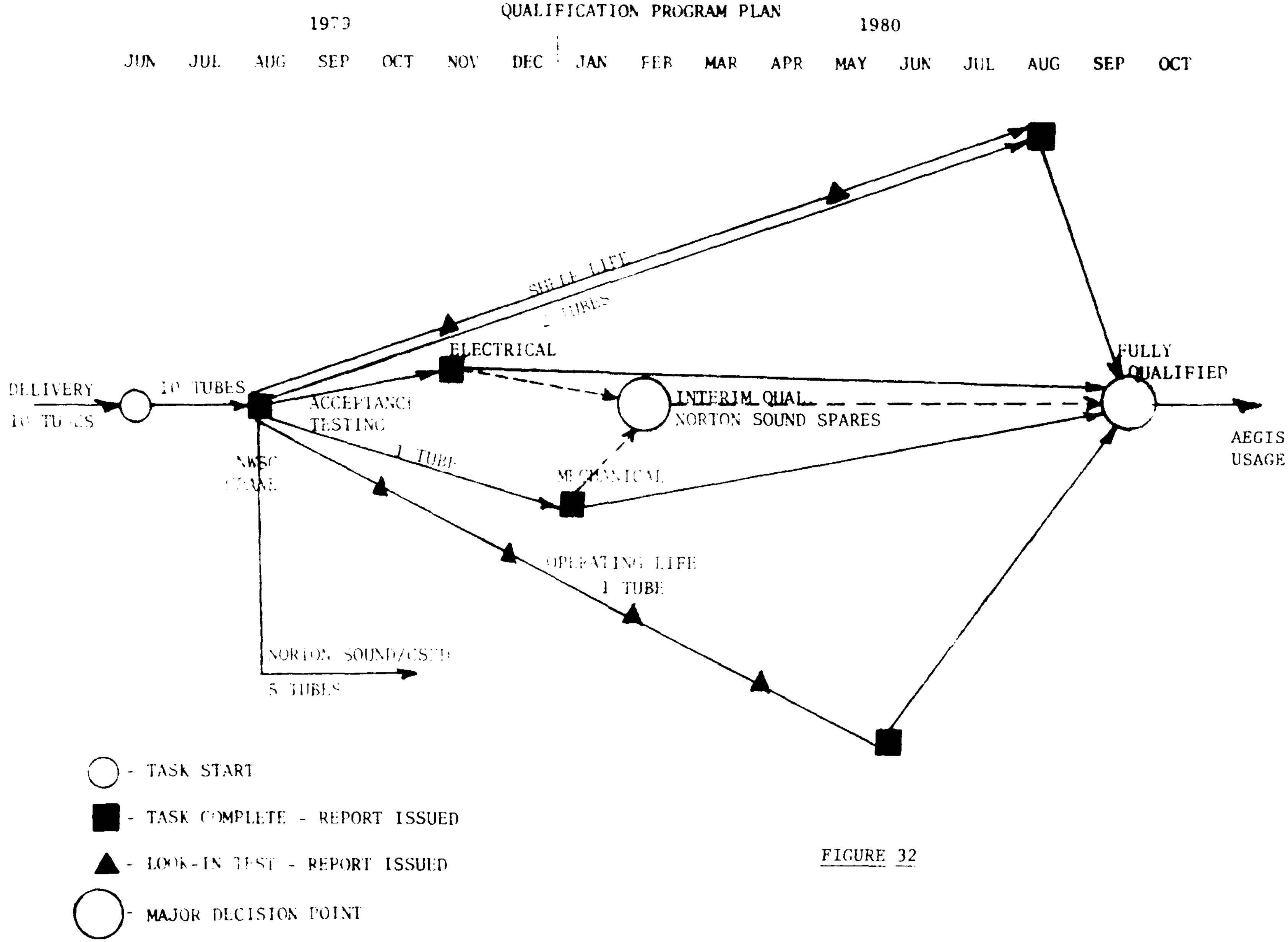

FIGURE 32

selected for shelf life testing. Tube S/N B102W has been given an interim test by application of vac-ion voltages after one month on the shelf. No problems are appearing. The remaining effort for shock and vibration is expected to take place in the November 1979 time frame. A tube has not yet been selected for that activity. All remaining tubes are so far still at Crane.

10.0 SFD-261 REPAIRABILITY

The SFD-261 crossed-field amplifier, was from the start, designed to be repairable. The major subassemblies which make up the high vacuum seal assembly are heliarc welded together in such a way that the weld can be machined opened for replacement of subassemblies and rewelded. There are several repair operations which have been conducted on the CFA without opening the high vacuum assembly. These are considered to be minor repairs. Any other repair which entails the opening of the high vacuum assembly is called a major repair.

From the information we presently have, the highest population of returned tubes will be in the minor repair category. The quality assurance practices presently followed in operating the Aegis system require that when a CFA is removed from its operating socket, it must be returned for inspection. This applies whether or not the fault which generated the replacement of the CFA is found to be CFA related. The highest population repair which has been done in the past is the replacement of damaged high voltage cables. The high voltage cable has since been redesigned, and this type of repair is expected to occur less frequently.

The redesigns which are incorporated into the MT tube were intended from the outset not to impair the repairability of the tube. In one area of the tube, that is the area dealing with the removal of the cathode assembly, the removal is slightly more difficult in the MT design than in the standard design, but it can still be done. The replacement of the cathode assembly is still possible

for at least three rebuilds. In addition, the redesign of the input and output window assemblies on the MT tube now permit the removal and replacement of damaged windows. Fortunately, there has been a very low incidence of this type of failure.

Shown in Table VI is a repair summary cost comparison of SFD-261 standard versus MT designs. The repairs are listed from the simpliest to the most complicated in that ascending order. In each case, the repair of the MT tube is equal to or less than the cost of repairing the standard tube.

We have not yet had sufficient experience with repaired tubes to be able to identify what the expected life time is of the various repair procedures. The first three repairs do not involve opening the high vacuum envelope of the tube and are minor repairs. It is not possible during these repair procedures, therefore, for a visual inspection of the slow wave circuit to be made. The life, therefore, remaining will depend strongly upon how many hours the tube had when it failed and whether or not the slow wave circuit was subjected to any degradation from temperature cycling.

Repair step 4, which is the replacement of the vac-ion pump and the oxygen dispenser, does involve the opening of the high vacuum envelope. It is intended as a simple rejuvenation for cathode depletion. It also will not permit a visual inspection of the slow wave circuit so that the prediction of life can only be predicated on failure mechanisms involving the cathode. One attempt

TABLE VI

REPAIR SUMMARY COST

COMPARISON OF SFD-261 STANDARD/MT

		SFD-261	SFD-261 MT
1.	Reage and Retest	$ 860	$ 860
2.	Replace High Voltage Cable	1,218	1,008
3.	Depackage Tube & Reposition Cathode	1,960	1,750
4.	Replace Vac-Ion Pump & Dispenser	3,565	3,355
5.	Clean Cathode & Rebuild	4,030	3,820
6.	Replace Cathode Assembly	5,110	4,190
7.	Replace Cathode & Pole Piece Assemblies	5,590	4,550
8.	Replace Input & Output Window Assemblies	N/A*	5,320

*Due to the complexity of the standard window and transformer design, the feasibility of replacing the window assemblies is not possible and, therefore, results in scrapping of the tube.

to execute this type of repair on a tube which had 9,000 hours on it was not successful. There is some question, therefore, that repair type 4 may not remain a viable type of repair.

Repair types 5 through 8 all involve opening the vacuum envelope and all will permit inspection of the slow wave circuit. Repair type 8 is stated simply as replacement of input and output window assemblies, but would also involve the removal of both pole piece and cathode assemblies prior to replacing the windows. Repair types 5 through 8 should result in a duplication or nearly so of new tube life expectancy.

Tubes are screened when returned to determine how far the repair effort need be taken. First the tubes are given a mechanical inspection to see if there has been mechanical damage to the tubes. Then the vac-ion pump is normally energized to establish that a high vacuum still exists inside the tube. If the vac-ion pump does not start, it either means that the vacuum is extremely good or extremely poor. In order to find out which, the tube would be installed in the master test set and an attempt would be made to transmit RF drive signals through the tube. If a collapse of the RF drive signal at the output of the CFA is observed, then the CFA has a very poor vacuum and is no longer a candidate for testing.

Occasionally, tubes are returned for poor performance, the cause of which has not been established. In such cases when it is determined that the tubes are operable, the first procedure, repair type 1, is attempted. Reaging simply refers to the operation

of the CFA in a cycled mode similar to that which the tubes see during burn-in. It has been found that this will sometimes restore the tube to normal operating conditions. Repair type 3 usually results from indications that there is a cathode insufficiency. The high vacuum seal assembly is removed from the permanent magnet package and is operated in an electromagnet. Efforts are then made to reposition the cathode to acquire specification performance.

It is presently difficult to estimate the distribution of the various types of repairs. Our best estimate, however, is as follows. Of 20 tubes which were returned, we estimate that the repairs which would be conducted would be in the following proportion from repair #1 through #8--10%, 10%, 10%, 5%, 30%, 15%, 10%, 0 and the remaining 10% would be found to be beyond economic repair. We project, therefore, that the most common failure mode will become one of cathode insufficiency which will be repairable by repair step #5 or repair step #6.

A program which supports the repair activities we have identified will support repairability of the complement of tubes on the Aegis program. No other special provisions are required in terms of modification of our plant or test equipment. Tubes undergoing repair can be injected in the appropriate place in the production cycle and take their place in the production line. Varian expects not only to have test equipment capacity for larger delivery rates than we have had in the past, and there will be sufficient capacity to include tubes returned for repair. It will also be important to maintain proper records with the repair histories of tubes so that

projections can be updated on the distribution of types of repairs.

11.0 CONCLUSIONS AND RECOMMENDATIONS

We believe that the program has succeeded in two ways: first, it has enabled some cost reduction measures to be introduced into the Aegis Lead Ship program on a zero risk basis resulting in a per-tube savings of about $5,000 per tube, and with lead ship being a 124-tube program, the resultant savings have already paid back the Navy investment not only in the present MT program but also the 1973-74 Cost Reduction program; and second, it has reduced the Aegis CFA price from a normalized 100 for the standard design to 57 for the MT tube. While inflation may seem to erode these gains in dollars, the savings realized are real. It was possible, even with the engineering effort which was applied to the program, to produce eleven (and a half) tubes within the contract price. This brings the tube unit price to about $19,000. The overall delays in the program were not of themselves harmful because there was no overrun, but they did, of course, delay the introduction of the MT design into the program.

Varian believes that the MT tube will have a life expectancy equal to or better than the standard deisgn; although it must be conceded that there is practically no life data. Varian is prepared to deliver the MT tube under the same warranty provisions as we have had on EDM-1, CSEDS and lead ship. We look forward to producing this design.

Varian recommends that the Navy proceed with the qualification test program it has underway at NWSC/Crane. But we have no reluctance to fielding a sample of MT tubes in parallel with the Crane program.

Appendix I

Silastic Potting Failure Report

-SILASTIC POTTING FAILURE REPORT-

PREPARED BY:

VARIAN ASSOCIATES, INC.

EIGHT SALEM ROAD

BEVERLY, MASSACHUSETTS 01915

19 APRIL 1979

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SILASTIC[1] POTTING FAILURE REPORT

1.0 INTRODUCTION

The purpose of this report is to summarize the activities relating to a class of failure which developed in September 1978 on the three programs in progress then for delivery of SFD-261H crossed-field amplifiers (CFA). These tubes were being delivered under contract No. N00164-78-C-0090 to the Naval Weapons Support Center, Crane, Indiana, and under purchase order Nos. 50-1757-AC-97001 and -97003 to the Raytheon Company, Wayland and Waltham, Massachusetts. Similar tubes were also in process on the Manufacturing Technology Program under contract No. N00123-77-C-1019, directed by Naval Ocean Systems Center, San Diego, California, and these tubes were also affected. Within a one-month period, four tubes out of approximately ten tubes which were in process in the test area failed. The failures all involved a high vacuum puncture of the high voltage ceramic bushing caused by corona and/or arcing. Corona and/or arcing are supposed to be suppressed by an encapsulation of room temperature, vulcanizing (RTV), silicone rubber called Silastic rubber. Adhesion of the rubber fails (if it was present to start with) and corona and/or arcing can occur in the space between the RTV rubber and the ceramic. The failures were of serious concern because of their numbers and also because they occurred very early in the life of the tube. NWSC/Crane

(1) Registered Trademark of Dow Corning

was requested not to operate any of the nine tubes which had been shipped to them until a recall could be considered.

2.0 DESCRIPTION OF THE FAILURES

Table I lists the failures by tube serial number and includes other relevant data. The serial numbers shown are Varian's in-process numbers. Tubes are assigned a 10000 series number after ATP. Tube number H168V (Cu) is a special unit with an all copper circuit (no molybdenum vane tips) being made for NWSC/Crane. A 150-hour burn-in period of on-off cycled operation is required on each tube prior to submitting the tube to the acceptance test procedure (ATP). The burn-in is done on one of six different test positions. Varian drawing C599047 shows the tube as it is just before it undergoes first electrical test in the electromagnet. The input waveguide and window have been omitted from the drawing so that the mini Vac-ion® pump can be clearly seen (Item 2 on the drawing). Item 9 points to the high voltage ceramic bushing, over which a primer is applied prior to casting the RTV rubber, Item 5. In each of the failed tubes, the cutting away of the Silastic revealed an absence of adhesion and, to varying degrees, discoloration, and burning as shown in Figure 1. In at least one tube a powder was also found between the ceramic and the Silastic. Each tube had a puncture of the high vacuum ceramic-to-metal seal.

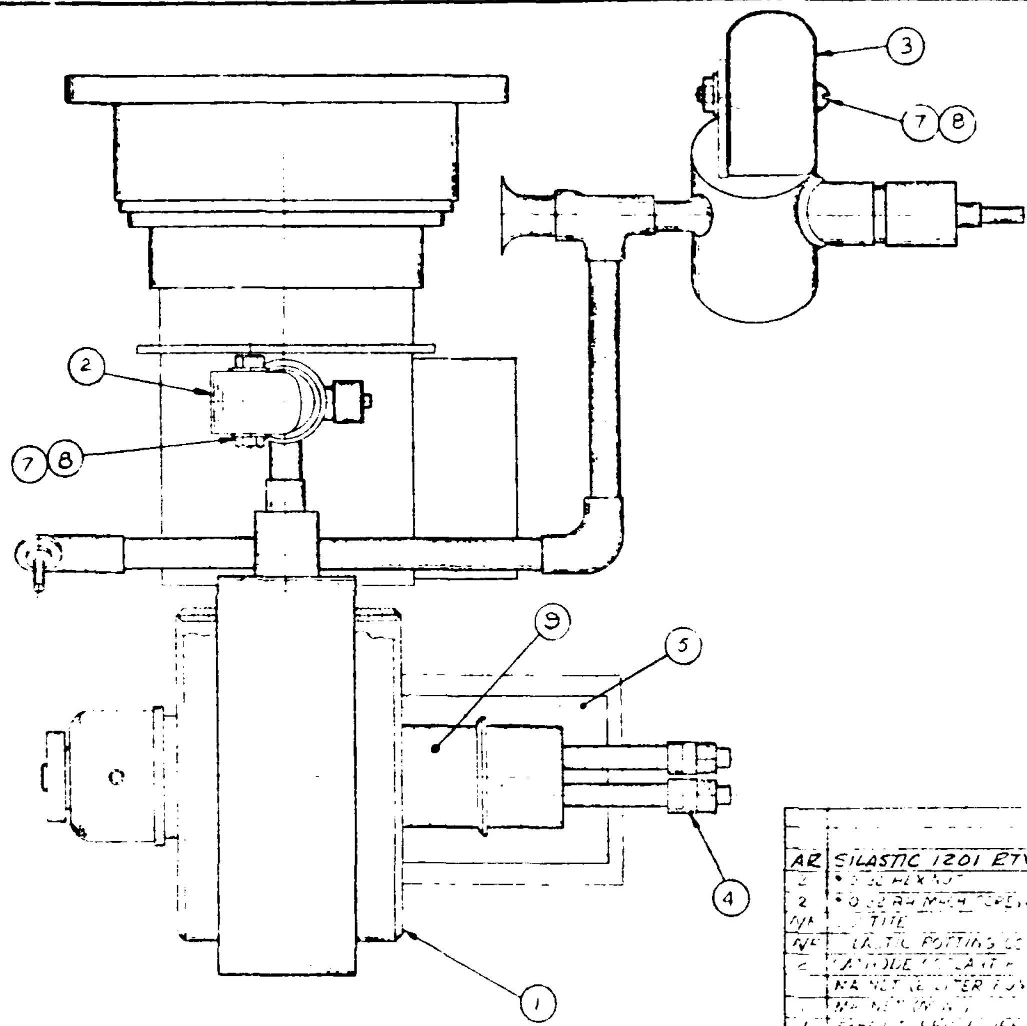
TABLE I

SUMMARY OF THE FAILURES

Body S/N	Date Failed	In What Process	Approx. Hrs. Pre-Condition	Burn-In Hours	Total Hours	Test Position
H168V (Cu)	8/31/78	Pre Burn-In	25	---	25	---
I29V	9/18/78	Burn-In	25	87	112	5
I312V	9/22/78	Burn-In	25	68.5	93.5	6
I164V	9/26/78	ATP	25	150	175	4/132 Hrs. 1/18 Hrs.

599047

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ADDED ITEM #9 PER ECO# 78-3214	10/[illegible]	[illegible]
	B	ADDED LOCATION OF 7&8 ECO# 79-3694	4/9/[illegible]	[illegible]



PLANT PROCESSING
SEE OPERATION SCHEDULE

QTY	DESCRIPTION	IDENTIFYING NO.	SPECIFICATION	MATERIAL	ITEM NO
AR	SILASTIC 1201 RTV PRIMER	A599217			9
2	• [illegible] HEX NUT				8
2	• [illegible] RH MACH SCREW				7
NR	[illegible]	A-[illegible]			6
NR	[illegible] POTTING COMPOUND	A-599017			5
2	CATHODE [illegible]	A-[illegible]			4
	MAGNET [illegible]	A-5[illegible]049			3
	MAGNET [illegible]	A-5[illegible]049			2
1	[illegible]	A-[illegible]			1

LIST OF MATERIALS

VARIAN/BEVERLY FABRICATION STANDARDS 302368 APPLIES TO THIS DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON

FRACTIONS	XX DECIMAL	XXX DECIMAL
± 1/64	.01	.005
ANGLES ± 0°30'	SURFACE QUALITY 63√ MAX	

MATERIAL

CONTRACT NO

DR [illegible]

CHK

APPD [illegible]

APPD

DESIGN ACTIVITY

varian/beverly

TESTABLE TUBE ASSEMBLY

SIZE	CODE IDENT NO	
C	88236	599047

SCALE 1/1 SHEET OF

NEXT ASSY	USED ON
599022	[illegible]

APPLICATION

AD-A085 043 VARIAN ASSOCIATES INC BEVERLY MA BEVERLY DIV F/G 9/5
SFD-261 CROSSED-FIELD AMPLIFIER MANUFACTURING TECHNOLOGY PROGRA--ETC(U)
SEP 79 R A LAPLANTE, F E TROJAN N00123-77-C-1019
UNCLASSIFIED 22-3040-FNL NL

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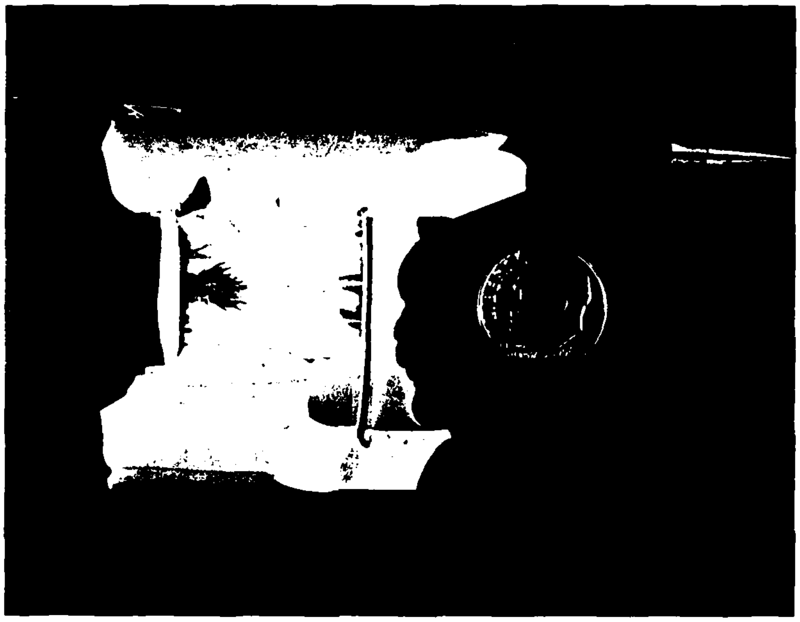

FIGURE 1

3.0 INVESTIGATION

3.1 Immediately after the failure of I164V on September 26, 1978, a hold was placed on all Silastic potting operations. Five other tubes, in various stages of testing, were dissected to see if there were variations in adhesion quality or evidence of corona. These tubes were H17V, I221V, I343V, I372V and I414V. H17V had been set aside for low power. Its Silastic had no adhesion and the ceramic was marked with arcing/corona marks. It was scrapped. I221V had Silastic which had no adhesion, but the ceramic was clean. The other three tubes had good adhesion and a clean ceramic.

3.2 Sample castings were made in simple molds and were dissected after curing for 24 hours. All of the sample castings exhibited good adhesion. Sample castings were made on stem pole piece assemblies, which include the high voltage ceramic. All of these castings had good adhesion. This suggested that the impairment of adhesion as well as the arcing/corona damage required that the CFA had undergone some period of RF operation. All of the tubes which were not normal did have some RF operating time ranging from 25 hours or so to 200 hours.

3.3 When production started in early 1978 on the SFD-261H for Aegis Production Program (APP) and NWSC/Crane spaces, some minor changes were made to the Silastic potting procedures. The changes were the addition of a color tracer to the primer undercoat to make it more visible to the potting operator, and the

addition of a second vacuum de-airing after the Silastic is poured around the ceramic bushing to eliminate air bubles which might be produced during the pouring. The Silastic used is Dow Corning DC 3112 used with Catalyst S. The primer is Dow Corning 1201. The primer is applied to the areas to be covered by the potting by brush. Since the primer color ranges from colorless to straw color it is difficult to see after application. It was not unreasonable to feel that the operator applying the primer may accidentally leave some areas uncoated and thereby produce a casting which has areas of poor adhesion.

Dow Corning recommended the addition of 0.05% by weight of Rhodamine B dye, manufactured by the J.T. Baker Chemical Company. The primer turns red and is much more easily seen after application.

Measured amounts of Silastic and catalyst are mixed in a beaker, and the beaker is de-aired by a mechanical vacuum pump in a small bell jar. A fixture which fits on the tube is then used for a second de-airing after the Silastic is cast.

3.4 Consultations were arranged with the manufacturer of the Silastic, and with Raytheon/Wayland and Varian/Palo Alto, both users of similar types of potting materials. The consultations with Dow Corning and Varian/Palo Alto led to some early confusion:

3.4.1 The first and second persons contacted at Dow Corning knew nothing about the microwave properties of Silastic or the primer, but the third person contacted

produced a Dow Corning data sheet listing the properties of Silastic at 1 MHz.

3.4.2 Contacts in Varian/Palo Alto indicated that excessive de-airing may remove volatile elements of the material and change its properties. Dow Corning said not.

3.4.3 Varian/Palo Alto indicated that we may not be allowing enough drying time for the primer, which is a function of relative humidity and can be as long as 6 hours. Dow Corning pointed out that it was true for 1200 primer which Varian/Palo Alto was using, but not true for 1201 primer, which Varian/Beverly uses.

3.4.4 No one contacted could comment on what effect is produced by exposing the material to microwave and high voltage fields.

3.4.5 One Dow Corning representative said that 1201 primer is moisture sensitive and another said it was not.

There was general agreement on several points:

3.4.6 Varian should carefully review the cleaning procedures used prior to potting.

3.4.7 Observe the shelf life restrictions on both the primer and Silastic.

3.4.8 The use of Rhodamine B dye is not part of the problem.

3.4.9 The powder residue is an arcing/corona combustion product.

One Dow Corning contact pointed out that one of the curing products of the Silastic is alcohol, and it is lossy at microwave frequencies. Suggested we allow longer curing times before operating the tubes.

Samples of the failed Silastic from tube numbers I221V (no adhesion) and I312V (failed) plus two simple castings were given to Raytheon/Sudbury for analysis. One of the castings had Rhodamine B dye in the primer and the other had clear primer. Energy dispersive X-ray analyses were performed on the samples, and parts of them were later subjected to pyrolysis at 800°F (the temperature at which the material is said to decompose). Details of the analyses are given in Raytheon memo TEB:78:79 dated 13 November 1978 by T.E. Baker. The conclusions reached were:

3.4.10 The failure occurred as a result of corona-induced and/or RF discharge induced mechanisms.

3.4.11 The powder residue is the result of combustion (exposure to high temperature).

3.4.12 The Rhodamine B dye probably had no influence on the mechanism leading to failure.

3.4.13 The presence of both high voltage fields and RF fields at the same time supports the corona/arcing mechanism.

3.4.14 Raytheon experience has been that corona discharge failures can occur very rapdily and supports the early-in-life occurrences we have had.

3.4.15 A thorough review of the cleaning and preparation procedures for the potting process is suggested.

3.5 Measurements of anode-to-cathode resistance were explored to see if they could be used to detect defects in the potting. Measurements were made on every CFA available at the time (including some from the CFA Design Study program, equipped with thermocouples and RF probes), a total of 19 tubes. All had seen RF operation, some only in an electromagnet; i.e., they had not been assembled in a permanent magnet package. A potential of 3000 volts was applied between anode and cathode, and the current was recorded. The current produced can have four components:

3.5.1 The leakage current across the normal anode-cathode insulator.

3.5.2 The leakage current, in packaged tubes, across the cathode coolant tubings, which are connected between the cathode and ground.

3.5.3 The current produced, in package tubes, by ion-pumping of the gas in the tube.

3.5.4 The leakage current across arc tracks in failed or about-to-fail tubes.

No evidence was found to suggest that a partly failed tube could be detected in this way. Tubes either had a resistance of less than 10 megohms (current greater than 30 μA) or much greater than 10 megohms (3 μA or 1000 megohms). The difficulty in separating the various current components also produces uncertainty in the measurement. Seven of the unpackaged tubes, for example, exhibited no current with 3000 volts applied!

3.6 An RF evaluation of the Rhodamine B tracer was also pursued. The test vehcile was an S-band, pill box, ceramic window as is used on the input and output of the SFD-261H. The technique used was to evaluate the effect on the Q of a window resonance of a coating of primer on the window with and without the tracer. Q's of the resonances were measured with the windows uncoated (two were used to improve the data sample size), coated with clear primer and coated with colored primer. The experimental errors caused by possible differences in coating thicknesses and the available measuring equipment made a quantitative evaluation difficult. It was clear, however, that the dye increased the microwave loss of the coatings in the two window assemblies. The effect of that increase on the dye's role in perhaps causing the failures was judged to be minimal. The absence of more significant changes in Q in these tests and uncertainty about RF electric field intensities in the coatings in an operating tube tended to support that judgement.

4.0 CORRECTIVE ACTION

The following are the corrective actions taken:

4.1 New cleaning procedures were established.

4.2 New primer (newly acquired primer) is to be used.

4.3 The Rhodamine B tracer was eliminated.

4.4 New handling procedures for the primer were issued.

4.5 A drying time for the primer coat was set.

4.6 The second vacuum de-airing was eliminated.

4.7 The procedure for pouring the rubber into the mold was clairifed to reduce possibility of air inclusions.

4.8 A cure time for the potting was established.

The above actions restored the basic procedure to that which was producing an acceptably low incidence of potting problems and added some general improvements.

5.0 RECALL/REWORK ACTIVITY

A summary of the recall/rework activity which followed is given in Table II. Nine tubes were recalled from NWSC/Crane and reworked. One of the nine, H52V/10007, had no adhesion and a marked ceramic. Two thermocouple tubes, replacements on a prior Raytheon order, S/N's G292U/10019 and I221V/10016, had no adhesion, but the ceramic was clean. Six APP tubes were reworked, of which one had good adhesion, three had fair adhesion and two had no adhesion. All ceramics were clean. One tube on the vane tip investigation program, I440V, had no adhesion and a clean ceramic. Two MT tubes had good adhesion. Twenty tubes in total were reworked

Body S/N	Tube S/N	Contract	Original Date	Condition Upon Depotting	Date Repotted	Comment
F431V-1	F431V-1	Crane	6/28/78	Good Adhesion. Clean Ceramic.	12/3/78	Skimmer tube. Recalled
G145V	10003	Crane	7/27/78	Good Adhesion. Clean Ceramic.	1/3/79	Recalled.
G206V-1	10006	Crane	8/10/78	Good Adhesion. Clean Ceramic.	1/2/79	Recalled.
G292V	10019	Raytheon	7/28/78	No Adhesion. Clean Ceramic.	11/10/78	Thermocouple tube.
H1V	10004	Crane	8/4/78	Good Adhesion. Clean Ceramic.	1/2/79	Recalled.
H17V	---	---	8/9/78	No Adhesion. Marked Ceramic.	---	Low power set aside. Scrapped.
H52V	10007	Crane	8/11/78	No Adhesion. Marked Ceramic.	1/3/79	Recalled.
H73V	10005	Crane	8/12/78	Good Adhesion. Clean Ceramic.	1/2/79	Recalled.
H239V	H239V	Crane	8/22/78	Good Adhesion. Clean Ceramic.	1/3/79	Recalled. All copper tube.
H269V	H269V	Crane	8/23/78	Good Adhesion. Clean Ceramic.	1/2/79	Recalled. Slotted vane tips.
H310V	H310V	Crane	8/24/78	Good Adhesion. Clean Ceramic.	1/3/79	Recalled. Slotted vane tips.

TABLE II

SUMMARY OF REPOTTING EFFORT (Excluding the Four Failures)

....continued

TABLE II--Summary of Repotting Effort (exluding the four failues) (continued)

Body S/N	Tube S/N	Contract	Original Date	Condition Upon Depotting	Date Repotted	Comment
I71V	10008	Raytheon	8/31/78	Fair Adhesion. Clean Ceramic.	12/19/78	
I114V	10009	Raytheon	9/5/78	No Adhesion Clean Ceramic.	12/18/78	
I221V	10016	Raytheon	9/7/78	No Adhesion Clean Ceramic.	10/5/78	Thermocouple tube.
I223V	10010	Raytheon	9/8/78	Fair Adhesion. Clean Ceramic.	12/11/78	Cost reduced cathode.
I286V	10011	Raytheon	9/11/78	Fair Adhesion. Clean Ceramic.	12/20/78	Cost reduced cathode.
I310V	10012	Raytheon	9/11/78	No Adhestion. Clean Ceramic.	12/15/78	
I343V	V343V	MT	9/13/78	Good Adhesion. Clean Ceramic.	10/17/78	
I372V	10013	Raytheon	9/14/78	Good Adhesion. Clean Ceramic.	10/4/78	
I414V	I414V	MT	9/15/78	Good Adhesion. Clean Ceramic.	10/17/78	
I440V	I440V	Raytheon	9/16/78	No Adhesion. Clean Ceramic.		Sputtered moly vane tip.

6.0 CONCLUSION

Although a number of factors contributing to the failures were identified, a single probable cause of failure was not identified. The composite effect of the contributors could probably have produced the failure pattern which was encountered. The corrective actions appear to have been effective. In addition to the twenty reworked tubes, more than 65 tubes on all programs using the new corrective actions have been potted and operated from 24 to 200 hours without a recurring potting failure.